JOURNAL
OF
AMERICAN CONCRETE INSTITUTE

VOL. II OCTOBER-NOVEMBER, 1914 No. 6

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PURPOSE OF THE INSTITUTE.

It is the purpose of the Institute, by means of conventions and publications, to increase and disseminate knowledge in regard to the use of cement, concrete and allied products; to conduct research into their properties and uses; and to formulate recommended practice and standard specifications.

Its objects are purely educational.

* In place of B. F. Affleck, resigned.
† In place of W. L. Church, resigned.

JOURNAL
OF
AMERICAN CONCRETE INSTITUTE

FOUNDED 1905, AND INCORPORATED 1906, AS
NATIONAL ASSOCIATION OF CEMENT USERS
CHARTER AMENDED JULY 2, 1913

The Institute is not responsible, as a body, for statements and opinions advanced in its publications

VOL. II OCTOBER-NOVEMBER, 1914 NO 6

ELEVENTH ANNUAL CONVENTION

The Eleventh Annual Convention of the Institute will be held at the Auditorium Hotel, Chicago, Ill., February 9–12, 1915. This Convention will mark the completion of the tenth year of the existence of the Institute, and an especially interesting and profitable program is being arranged. The sessions will be at 10 A. M., 3 P. M. and 8 P. M.

Summary of Program, Eleventh Annual Convention

Tuesday, February 9, 1915.

Concrete Roads, Sidewalks and Bridges. Important papers and discussions relating to the status of concrete road construction in the United States will be presented, and special attention given to costs, repairs and maintenance.

Wednesday, February 10, 1915.

Concrete and Reinforced Concrete Tests and Design. Discussion of the very important column tests made by the Institute at Pittsburgh, tests of buildings, and other matters of current special interest.

Thursday, February 11, 1915.

Concrete in Art and Architecture. Discussion of architectural design in concrete, dimension and art concrete stone, treatment of surfaces, etc.

Banquet. The Annual Banquet in the evening will have a special program in celebration of the completion of the tenth year of the existence of the Institute.

Friday, February 12, 1915.

Plant Management and Costs. This day will be devoted to concreting plants, covering plant management and costs, the design and cost of wood and metal forms, and the methods of placing, proportioning and selection of concrete materials.

The Convention promises to be one of unusual interest, and the members are urged to keep the dates in mind, make arrangements to attend and bring with them others who should be interested in the work of the Institute.

Letter Ballot on By-Laws and Specifications.

The following matters were referred to letter ballot at the Chicago Convention:

1. Proposed Revision of the By-Laws.
   The present By-Laws are printed in full on pp. 6–10 of Journal, Vol. I, No. 2, and the proposed amendments on pp. 5 of this issue.
2. Proposed Standard Specifications for One Course Concrete Highways.
   The proposed Specifications appear on pp. 7–16.
3. Proposed Standard Specifications for One Course Concrete Street Pavement.
   The proposed Specifications appear on pp. 17–26.
4. Proposed Standard Specifications for Two Course Concrete Street Pavement.
   The proposed Specifications appear on pp. 27–37.
5. Proposed Revision of Standard Specifications for Portland Cement Stucco on Metal Lath, Brick, Tile and Concrete Block.
   The revised Specifications appear on pp. 38–46. The separate items of the revision appear on p. 12 of Journal, Vol. I, No. 2.

PLEASE FILL OUT, SIGN AND RETURN THE ENCLOSED BALLOT AT ONCE.

Ballot for Members of Committee on Nomination of Officers.

In carrying out the provision of the amendment to the By-Laws as set forth under Item 1, there is enclosed herewith a ballot for members of the Committee on Nomination of Officers, which is to be canvassed on December 10.

PROPOSED AMENDMENTS TO BY-LAWS.

Change word "Association" to "Institute" wherever it occurs.

ARTICLE II.

SEC. 3. Insert a new Section 3 to read as follows and renumber old sections 3–12 to 4–13.

SEC. 3 (new). There shall be a Committee of five members on Nomination of Officers, elected by letter ballot of the members of the Institute, which is to be canvassed by the Board of Direction on or before September 1 of each year.

The Committee on Nomination of Officers shall select by letter ballot of its members, candidates for the various offices to become vacant at the next Annual Convention and report the result to the Board of Direction who shall transmit the same to the members of the Institute at least 60 days prior to the Annual Convention. Upon petition signed by at least ten members, additional nominations may be made within 20 days thereafter. The consent of all candidates must be obtained before nomination. The complete list of candidates thus nominated shall be submitted 30 days before the Annual Convention to the members of the Institute for letter ballot, to be canvassed at 12 o'clock noon on the second day of the Convention and the result shall be announced the next day at a business session.

SEC. 4. Amend by striking out the words "appoint the Secretary" and insert the following:

"Have general supervision of the affairs of the Institute and at the first meeting following its election, appoint a Secretary and from its own members a Finance Committee of three."

SEC. 5. Strike out the present wording and substitute the following:

"It shall be the duty of the Finance Committee to prepare the annual budget and to pass on proposed expenditures before their submission to the Board of Direction. The accounts of the Secretary and Treasurer shall be audited annually."

SEC. 6. Strike out words:
"A Committee on Nomination of Officers and."

SEC. 9. Revise first sentence to read:
"The President shall perform the usual duties of the office."

SEC. 10. Revise to read:
"The Secretary shall be the general business agent of the Institute, shall perform such duties and shall furnish such bond as may be determined by the Board of Direction."

ARTICLE III.

SEC. 2. Amend by striking out the words "immediately after" and substitute "during," and strike out the word "was" and substitute "is."

NOTE:—The present By-Laws are printed in full on pp. 6-10 of JOURNAL, Vol. I, No. 2.

STANDARD No. 5.

AMERICAN CONCRETE INSTITUTE

Founded 1905 and Incorporated 1906, as
NATIONAL ASSOCIATION OF CEMENT USERS
Charter Amended July 2, 1913.

PHILADELPHIA, PA.

PROPOSED STANDARD SPECIFICATIONS FOR ONE COURSE CONCRETE HIGHWAY.

I. MATERIALS.

Cement.

1. The *cement* shall meet the requirements of the Standard Specifications for Portland Cement, adopted by the American Society for Testing Materials, August 16, 1909, with all subsequent amendments and additions thereto adopted by said Society, and adopted by this Institute (Standard No. 1).

When the cement is not inspected at the place of manufacture it shall be stored a sufficient length of time to permit of inspecting and testing. The engineer shall be notified of the receipt of each shipment of cement.

Aggregate.

2. *Fine aggregate* shall consist of sand or screenings from clean, hard, durable, crushed rock or gravel consisting of quartzite grains or other equally hard material graded from fine to coarse, with the coarse particles predominating and passing, when dry, a screen having $\frac{1}{4}$-inch openings. It shall be clean, hard, free from dust, loam, vegetable, or other deleterious matter. Not more than twenty (20) per cent shall pass a sieve having fifty (50) meshes per linear inch, and not more than five (5) per cent shall pass a sieve having one hundred (100) meshes per linear inch.

Fine aggregate containing more than three (3) per cent of clay or loam shall be washed before using.

Fine aggregate shall be of such quality that the mortar composed of one (1) part Portland cement and three (3) parts fine aggregate by weight, when made into briquettes, shall show a tensile strength at least equal to the strength of 1 to 3 mortar of the same consistency made with the same cement and Standard Ottawa sand.

In no case shall fine aggregate containing frost or lumps of frozen material be used.

3. *Coarse aggregate* shall consist of clean, hard, durable, crushed rock or gravel, graded in size, free from dust, loam, vegetable, or other deleterious matter, and shall contain no soft, flat or elongated particles. The size of the coarse aggregate shall be such as to pass a one and one-half ($1\frac{1}{2}$) inch round opening and be retained on a screen having one-quarter ($\frac{1}{4}$) inch openings. In no case shall coarse aggregate containing frost or lumps of frozen material be used.

4. *Natural mixed aggregate* shall not be used as it comes from deposits, but shall be screened and used as specified.

Water. 5. *Water* shall be clean, free from oil, acid, alkali, or vegetable matter.

Reinforcement. 6. *Reinforcement.*—Concrete pavements twenty (20) feet or more in width shall be reinforced with metal fabric. All reinforcement shall be free from excessive rust, scale, paint, or coatings of any character which will tend to destroy the bond. All reinforcement shall develop an ultimate tensile strength of not less than 70,000 pounds per square inch and bend 180 deg. around one diameter and straighten without fracture.

Joint Filler. 7. *Joint Filler* shall consist of prepared felt or similar material of approved quality having a thickness of not less than $\frac{1}{8}$ nor more than $\frac{1}{4}$ in.

Joint Protection Plates. 8. *Joint Protection Plates.*—Soft steel plates for the protection of the edges of the concrete at transverse joints shall be not less than $2\frac{1}{2}$ in. in depth and not less than $\frac{1}{8}$ in. at any point nor more than $\frac{1}{4}$ in. in average thickness. The plates shall be of such form as to provide for rigid anchorage to the concrete. The type and method of installation of joint protection plates shall be approved by the engineer.

Shoulders. 9. *Shoulders.*—Materials for the construction of shoulders shall be approved by the engineer.

II. GRADING.

10. *Defined.*—The term "grading" shall include all cuts, fills, ditches, borrow pits, approaches and all earth moving for whatever purpose, where such work is an essential part of or necessary to the prosecution of the contract. When to bring the

surface to grade, a fill of one (1) foot or less is required, the area shall be thoroughly grubbed. All soft, spongy or yielding spots and all vegetable or other objectionable matter shall be removed and the space refilled with suitable material.

11. *Stakes* will be set by the engineer for center line, side of slopes, finished grade and other necessary points properly marked for the cut or fill. **Engineer's Stakes.**

12. *Excess material* shall be disposed of as directed by the engineer, the free haul not to exceed.....feet. **Excess Material.**

13. *Over-haul.*—Materials hauled a greater distance than the free haul from the place of excavation shall be paid for at the rate of.....cents per cubic yard for each additional .....feet.

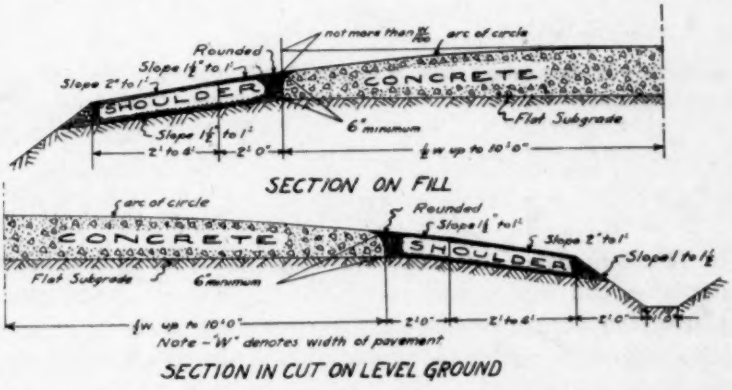


FIG. 1.—ONE COURSE CONCRETE HIGHWAY. SECTIONS ON FILL AND CUT.

14. *Fills.*—Embankments shall be formed of earth or other approved materials and shall be constructed in successive layers, the first of which shall extend entirely across from the toe of the slope on one side to the toe of the slope on the other side, and successive layers shall extend entirely across the embankments from slope to slope. Each layer, which shall not exceed one (1) foot in depth, shall be thoroughly rolled with a roller weighing not less than five (5) tons nor more than ten (10) tons before the succeeding layer is placed. The roller shall pass over the entire area of the fill at least twice. **Fills.**

The sides of the embankment shall be kept lower than the

center during all stages of the work, and the surface maintained in condition for adequate drainage. The use of muck, quicksand, soft clay or spongy material which will not consolidate under the roller, is prohibited.

When the material excavated from cuts is not sufficient to make the fills shown on the plans, the contractor shall furnish the necessary extra material to bring the fills to the proper width and grade. When the earth work is completed the cross-section of the road shall conform to the cross-sectional drawings and profile shown in Fig. 1.

Slopes.

15. All *slopes* shall be properly dressed to lines given by the engineer.

Finished Grade.

16. *Finished Grade.*—When grade line is approached, the final grade stakes will be set, for which sufficient notice must be given to the engineer.

NOTE.—In excavating cuts, it is considered advisable, when the line of the sub-grade is approached, to compact the remaining material by rolling. The depth of material left in the cut to be compressed to the finished grade by rolling will depend upon the character of the material.

III. DRAINAGE.

Drainage.

17. *Drainage.*—The contractor shall construct such drainage ditches as will insure perfect sub- and surface-drainage during construction and such work shall be completed to the satisfaction of the engineer, prior to the preparation of the roadbed, as herein specified.

Tile drains shall be placed as shown in the drawings attached hereto. Tile to be laid in the trench at least..... (.....) inches wide and.....(.....) feet deep below the established grade of the finished pavement. Such trench shall be back filled with crushed stone or pit run gravel, with sand removed, which after light tamping shall be .....(.....) inches in depth.

Open ditches must be constructed along the concrete road as shown in Fig. 1, the dimensions, side slopes and grade of said ditches being as shown on the cross-section and profile.

At the time of the acceptance of the road, the ditches must be in perfect condition, with clean slopes and bottom, containing no obstructions to the flow of water.

IV. SUB-GRADE.

Sub-Grade

18. *Construction.*—The bottom of the excavation or top of the fill, when completed, shall be known as the sub-grade, and shall be at all places true to the elevation as shown on the plans attached hereto.

The roadway shall be graded to the proper sub-grade to permit of the specified thickness of paving materials being laid to bring the finished surface of the pavement to the lines and grades as shown on the plans.

The sub-grade shall be brought to a firm, unyielding surface by rolling the entire area with a self-propelled roller weighing not less than ten (10) tons, and all portions of the surface of the sub-grade which are inaccessible to the roller shall be thoroughly tamped with a hand tamp weighing not less than fifty (50) pounds, the face of which shall not exceed 100 square inches in area. All soft, spongy or yielding spots and all vegetable or other objectionable matter shall be entirely removed and the space refilled with suitable material.

Where considered necessary or of assistance in producing a compact, solid surface, the sub-grade before being rolled shall be well sprinkled with water.

When the concrete pavement is to be constructed over an old roadbed composed of gravel or macadam, and the concrete is to be wider than the old gravel or macadam road, the latter shall be entirely loosened and the material spread for the full width of the roadbed and rolled. All interstices shall be filled with fine material, and rolled to make a dense, tight surface of the roadbed.

19. *Acceptance.*—No concrete shall be deposited upon the sub-grade until it is checked and accepted by the engineer.

20. *Completion.*—Upon the sub-grade thus formed shall be laid the concrete pavement as shown in Fig. 1.

V. FORMS.

Forms.

21. *Materials.*—The forms shall be free from warp, of sufficient strength to resist springing out of shape, and shall be equal in width to the thickness of the pavement at the edges. Wooden forms shall be of not less than two (2) inch stock and shall be capped with two (2) inch angle iron.

22. *Setting.*—The forms shall be well staked or otherwise held to the established line and grades, and the upper edges shall conform to the established grade of the road.

23. *Treatment.*—All mortar and dirt shall be removed from the forms that have previously been used.

VI. PAVEMENT SECTION.

Pavement Section.

24. *Width, Thickness of Concrete and Crown.*—The concrete pavement shall be.....feet wide,..... .....(.....) inches in depth at center, and..... .....(.....) inches in depth at the sides. The finished surface shall conform to the arc of a circle, as shown on Fig. 1.

NOTE.—Crown shall be not more than one-one-hundredth (1/100) of the width. The thickness of the concrete at the edges shall not be less than six (6) inches.

VII. JOINTS.

Joints.

25. *Width and Location.*—Transverse joints shall be not less than one-quarter ($\frac{1}{4}$) inch nor more than three-eighths ($\frac{3}{8}$) inch in width and shall be placed across the pavement perpendicular to the center line, not more than 35 feet apart. When a curb is specified or where pavement abuts a building a joint not less than one-quarter ($\frac{1}{4}$) inch wide shall be placed between it and the pavement. All joints shall extend through the entire thickness of the pavement and shall be perpendicular to its surface.

26. *Protection of Joints.*—The concrete at transverse joints shall be protected with soft steel joint protection plates which shall be rigidly anchored to the concrete. The installation of the metal protection plates shall meet with the approval of the engineer. The surface edges of the metal plates shall conform to the finished surface of the concrete, as shown in Fig. 1.

All joints over one-quarter ($\frac{1}{4}$) inch high or one-half ($\frac{1}{2}$) inch low shall be removed.

27. *Joint Filler.*—All joints shall be formed by inserting during construction and leaving in place the required thickness of joint filler which shall extend through the entire thickness of the pavement.

VIII. MEASURING MATERIALS AND MIXING CONCRETE.

28. *Measuring.*—The method of measuring the materials for the concrete, including water, shall be one which will insure separate and uniform proportions of each of the materials at all times. A bag of Portland cement (94 lbs. net) shall be considered one (1) cubic foot. **Measuring Materials.**

29. *Mixing.*—The materials shall be mixed to the desired consistency in a batch mixer of approved type, and mixing shall continue for at least forty-five (45) seconds after all materials are in the drum. The drum shall be completely emptied before mixing successive batches. The drum of the mixer used shall revolve at a speed not less than the minimum nor more than the maximum number of revolutions shown in the following table: **Mixing.**

Rated Capacity, cu. ft. Unmixed Material.	Capacity, Bags of Cement in 1 : 2 : 3 mix.	Revolutions per Minute of Drum. Min.	Max.
7 to 11	1	15	21
12 to 17	2	12	20
18 to 23	3	12	20
24 to 29	4	11	17
30 to 33	5	10	15

30. *Retempering* of mortar or concrete which has partially hardened, that is, mixing with additional materials or water, shall not be permitted. **Retempering.**

31. *Proportions.*—The concrete shall be mixed in the proportions of one (1) bag of Portland cement to not more than two (2) cubic feet of fine aggregate and not more than three (3) cubic feet of coarse aggregate, and in no case shall the volume of the fine aggregate be less than one-half ($\frac{1}{2}$) the volume of the coarse aggregate. **Proportions.**

A cubic yard of concrete in place between neat lines shall contain not less than one and seven-tenths (1.7) barrels of cement.

The engineer shall compare the calculated amount of cement required according to these specifications and plans attached hereto with the amounts actually used in each section of concrete between successive transverse joints, as determined by actual count of the number of bags of cement used in each section. If the amount of cement used in any three adjacent sections (between transverse joints) is less by two (2) per cent, or if the amount of

cement used in any one section is less by five (5) per cent, than the amount hereinbefore specified, the contractor agrees to remove all such sections and to rebuild the same according to these specifications at his expense.

Consistency.

32. *Consistency.*—The materials shall be mixed with sufficient water to produce a concrete which when deposited will settle to a flattened mass, but shall not be so wet as to cause a separation of the mortar from the coarse aggregate in handling.

IX. REINFORCING.

Reinforcing.

33. *Reinforcing.*—Concrete pavements twenty (20) feet or more in width shall be reinforced. The cross-sectional area of the reinforcing metal running parallel to the center line of the pavement shall amount to at least 0.038 square inch per foot of pavement width and the cross-sectional area of reinforcing metal, which is perpendicular to the center line of the pavement, shall amount to at least 0.049 square inch per foot of pavement length.

Reinforcing metal shall not be placed less than two (2) inches from the finished surface of the pavement and otherwise shall be placed as shown on the drawings. The reinforcing metal shall extend to within two (2) inches of all joints, but shall not cross them. Adjacent widths of fabric shall be lapped not less than four (4) inches.

X. PLACING CONCRETE.

Placing Concrete

34. *Placing.*—Immediately prior to placing the concrete, the sub-grade shall be brought to an even surface. The surface of the sub-grade shall be thoroughly wet when the concrete is placed.

After mixing, the concrete shall be deposited rapidly in successive batches upon the sub-grade prepared as hereinbefore specified. The concrete shall be deposited to the required depth and for the entire width of the pavement, in a continuous operation, between transverse joints without the use of intermediate forms or bulkheads.

In case of a breakdown concrete shall be mixed by hand to complete the section or an intermediate transverse joint placed as hereinbefore specified at the point of stopping work. Any concrete in excess of that needed to complete a section at the stopping of work shall not be used in the work.

35. *Finishing.*—The surface of the concrete shall be struck off by means of a template or strike board which shall be moved with a combined longitudinal and cross-wise motion. When the strike board is within three (3) feet of a transverse joint it shall be lifted to the joint and the pavement struck by moving the strike board away from the joint; any excess concrete shall be removed. Concrete adjoining the metal protection plates at transverse joints shall be dense in character and any holes left by removing any device used in installing the metal protection plates shall be immediately filled with concrete.

After being brought to the established grade with the template or strike board, the concrete shall be finished from a suitable bridge, no part of which shall come in contact with the concrete. The concrete shall be finished with a wood float in a manner to thoroughly compact it and produce a surface free from depressions or inequalities of any kind. The finished surface of the pavement shall not vary more than one-quarter ($\frac{1}{4}$) inch from the true shape.

The edges of the pavement shall be rounded as shown in Fig. 1.

XI. PROTECTION.

36. *Curing and Protection.*—Excepting as hereinafter specified, the surface of the pavement shall be sprayed with water as soon as the concrete is sufficiently hardened to prevent pitting, and shall be kept wet until an earth covering is placed. As soon as it can be done without damaging the concrete, the surface of the pavement shall be covered with not less than two inches of earth or other material which will afford equally good protection, which cover shall be kept moist for at least ten (10) days. When deemed necessary or advisable by the engineer, freshly laid concrete shall be protected by a canvas covering until the earth covering can be placed. Protection.

If at the time the pavement is laid or during the period of curing the temperature during the daytime drops below 50 degrees Fahrenheit, sprinkling and covering of the pavement shall be omitted at the direction of the engineer.

Under the most favorable conditions for hardening, in hot weather, the pavement shall be closed to traffic for at least fourteen (14) days, and in cool weather for an additional time, to be determined by the engineer.

The contractor shall erect and maintain suitable barriers to protect the concrete from traffic, and any part of the pavement damaged from traffic or other causes occurring prior to its official acceptance, shall be repaired or replaced by the contractor at his expense in a manner satisfactory to the engineer.

Before the pavement is thrown open to traffic the covering shall be removed and disposed of as directed by the engineer.

Freezing.

37. *Temperature Below 35 Degrees Fahrenheit.*—Concrete shall not be mixed or deposited when the temperature is below freezing.

If at any time during the progress of the work the temperature is, or in the opinion of the engineer will within twenty-four (24) hours drop to 35 degrees Fahrenheit, the water and aggregates shall be heated and precautions taken to protect the work from freezing for at least ten (10) days. In no case shall concrete be deposited upon a frozen sub-grade.

XII. SHOULDERS.

Shoulders.

38. *Construction.*—Where shoulders are required they shall be built upon the properly prepared sub-grade, as shown on the cross-sectional drawing, Fig. 1. The work shall be done to the entire satisfaction of the engineer.

AMERICAN CONCRETE INSTITUTE

Founded 1905 and Incorporated 1906, as
NATIONAL ASSOCIATION OF CEMENT USERS
Charter Amended July 2, 1913.

PHILADELPHIA, PA.

PROPOSED STANDARD SPECIFICATIONS FOR ONE COURSE CONCRETE STREET PAVEMENT.

I. MATERIALS.

Cement.

1. The *cement* shall meet the requirements of the Standard Specifications for Portland Cement, adopted by the American Society for Testing Materials, August 16, 1909, with all subsequent amendments and additions thereto adopted by said society and adopted by this Institute (Standard No. 1).

When the cement is not inspected at the place of manufacture, it shall be stored a sufficient length of time to permit of inspecting and testing. The engineer shall be notified of the receipt of each shipment of cement.

Fine Aggregate.

2. *Fine aggregate* shall consist of sand or screenings from clean, hard, durable, crushed rock or gravel consisting of quartzite grains or other equally hard material graded from fine to coarse with the coarse particles predominating and passing, when dry, a screen having $\frac{1}{4}$-inch openings. It shall be clean, hard, free from dust, loam, vegetable, or other deleterious matter. Not more than twenty (20) per cent shall pass a sieve having fifty (50) meshes per linear inch, and not more than five (5) per cent shall pass a sieve having one hundred (100) meshes per linear inch.

Fine aggregate containing more than three (3) per cent of clay or loam shall be washed before using.

Fine aggregate shall be of such quality that the mortar composed of one part Portland cement and three (3) parts fine aggregate by weight when made into briquettes, shall show a tensile strength at least equal to the strength of 1 to 3 mortar of the same consistency made with the same cement and Standard Ottawa sand.

Coarse Aggregate.

In no case shall fine aggregate containing frost or lumps of frozen material be used.

3. *Coarse aggregate* shall consist of clean, hard, durable, crushed rock or gravel, graded in size, free from dust, loam, vegetable or other deleterious matter and shall contain no soft, flat or elongated particles. The size of the coarse aggregate shall be such as to pass a one and one-half ($1\frac{1}{2}$) inch round opening and be retained on a screen having one-quarter ($\frac{1}{4}$) inch openings. In no case shall coarse aggregate containing frost or lumps of frozen material be used.

Natural Mixed Aggregate.

4. *Natural mixed aggregate* shall not be used as it comes from deposits but shall be screened and used as specified.

Water.

5. *Water* shall be clean, free from oil, acid, alkali or vegetable matter.

Reinforcement.

6. *Reinforcement.*—Concrete pavements twenty (20) feet or more in width shall be reinforced with metal fabric. All reinforcement shall be free from excessive rust, scale, paint or coatings of any character which will tend to destroy the bond. All reinforcement shall develop an ultimate tensile strength of not less than 70,000 pounds per square inch and bend 180 deg. around one diameter and straighten without fracture.

Joint Filler.

7. *Joint Filler* shall consist of prepared felt or similar material of approved quality having a thickness of not less than $\frac{1}{8}$ nor more than $\frac{1}{4}$ in.

Joint Protection Plates.

8. *Joint Protection Plates.*—Soft steel plates for the protection of the edges of the concrete at transverse joints shall be not less than $2\frac{1}{2}$ in. in depth and not less than $\frac{1}{8}$ in. at any point nor more than $\frac{1}{4}$ in. in average thickness. The plates shall be of such form as to provide for rigid anchorage to the concrete. The type and method of installation of joint protection plates shall be approved by the engineer.

Shoulders.

9. *Shoulders.*—Materials for the construction of shoulders shall be approved by the engineer.

II. GRADING.

10. *Defined.*—The term "grading" shall include all cuts, fills, approaches and all earth moving for whatever purpose where such work is an essential part of or necessary to the prosecution

of the contract. When to bring the surface to grade, a fill of one (1) foot or less is required, the area shall be thoroughly grubbed. All soft, spongy or yielding spots and all vegetable or other objectionable matter shall be removed and the space refilled with suitable material.

Engineer's Stakes.

11. *Stakes* will be set by the engineer for the center line, side of slopes, finished grade and other necessary points properly marked for the cut or fill.

Excess Material.

12. *Excess Material* shall be disposed of as directed by the engineer, the free haul not to exceed ..... feet.

13. *Over-haul.*—Materials hauled a greater distance than the free haul from the place of excavation shall be paid for at the

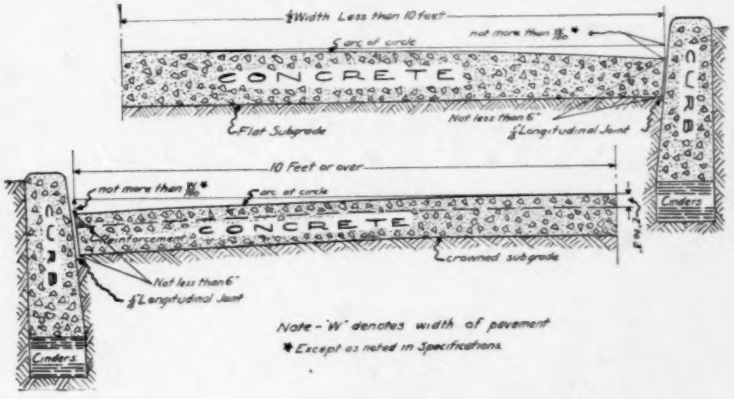


FIG. 1.—ONE COURSE CONCRETE PAVEMENT.

rate of ..... cents per cubic yard for each additional ..... feet.

Fills.

14. *Fills.*—Embankments shall be formed of earth or other approved materials and shall be constructed in successive layers, the first of which shall extend entirely across from the toe of the slope on one side to the toe of the slope on the other side, and successive layers shall extend entirely across the embankments from slope to slope. Each layer, which shall not exceed one (1) foot in depth, shall be thoroughly rolled with a roller weighing not less than five (5) tons nor more than ten (10) tons before the succeeding layer is placed. The roller shall pass over the entire area of the fill at least twice.

The sides of the embankment shall be kept lower than the center during all stages of the work and the surface maintained in condition for adequate drainage. The use of muck, quicksand, soft clay or spongy material which will not consolidate under the roller is prohibited.

When the material excavated from the cuts is not sufficient to make the fills shown on the plans, the contractor shall furnish the necessary extra material to bring the fills to the proper width and grade. When the earth work is completed, the cross-section of the road shall conform to the cross-sectional drawings and profile shown in Fig. 1.

Slopes.

15. All *slopes* must be properly dressed to a line given by the engineer.

Finished Grade.

16. *Finished Grade.*—When the grade line is approached the final grade stakes will be set, for which sufficient notice must be given to the engineer.

NOTE.—In excavating cuts, it is considered advisable, when the line of the sub-grade is approached, to compact the remaining material by rolling. The depth of material left in the cut to be compressed to the finished grade by rolling, will depend upon the character of the material.

III. DRAINAGE.

Drainage.

17. *Drainage.*—The contractor shall construct tile or other drains as shown in the drawings attached hereto. Tile to be laid in the trench at least ..... (.....) inches wide, and ..... (.....) feet deep below the top of the adjacent curb. Such trench shall be back filled with crushed stone or pit run gravel with sand removed, which after light tamping shall be ..... (.....) inches in depth.

Catch Basins.

18. All *catch basin* and *manhole tops* and all covers of openings of any kind shall be readjusted to the grade by the contractor at his expense.

IV. SUB-GRADE.

Sub-Grade.

19. *Construction.*—The bottom of the excavation or the top of the fill when completed shall be known as the sub-grade and shall be at all places true to the elevation as shown on the plans attached hereto.

The street shall be graded from curb to curb to the proper sub-grade to permit of the specified thickness of paving materials being laid to bring the finished surface of the pavement to the lines and grades as shown on the plans.

The sub-grade shall be brought to a firm, unyielding surface by rolling the entire area with a self-propelled roller weighing not less than ten (10) tons, and all portions of the surface of the sub-grade which are inaccessible to the roller shall be thoroughly tamped with a hand tamp weighing not less than fifty (50) pounds, the face of which shall not exceed 100 square inches in area. All soft, spongy or yielding spots and all vegetable or other objectionable matter shall be entirely removed and the space refilled with suitable material.

Where considered necessary or of assistance in producing a compact solid surface the sub-grade, before being rolled, shall be well sprinkled with water.

When the concrete pavement is to be constructed over an old roadbed composed of gravel or macadam, and the concrete is to be wider than the old gravel or macadam road, the latter shall be entirely loosened and the material spread for the full width of the roadbed and rolled. All interstices shall be filled with fine material, and rolled to make a dense, tight surface of the road-bed.

20. *Acceptance.*—No concrete shall be deposited upon the sub-grade until it is checked and accepted by the engineer.

21. *Completion.*—Upon the sub-grade thus formed shall be laid the concrete pavement as shown in Fig. 1.

V. FORMS.

22. *Materials.*—The forms shall be free from warp, of sufficient strength to resist springing out of shape, and shall be equal in width to the thickness of the pavement at the edges. Wooden forms shall be of not less than two (2) inch stock and shall be capped with two (2) inch angle iron. Forms.

23. *Setting.*—The forms when required shall be well staked or otherwise held to the established line and grades and the upper edges shall conform to the established grade of the street.

24. *Treatment.*—All mortar and dirt shall be removed from the forms that have been previously used.

VI. PAVEMENT SECTION.

Pavement Section.

25. *Width, Thickness of Concrete and Crown.*—The concrete pavement shall be ..... feet wide ..... (.....) inches in depth at center and ..... (.....) inches in depth at the sides. The finished surface shall conform to the arc of a circle as shown on the plans attached hereto.

NOTE.—The thickness of the concrete at the edges shall not be less than six (6) inches. When pavements twenty (20) feet or less in width are to be built on approximately level ground and a flat sub-grade is to be used sufficient fall for drainage at the sides of the pavement along the curb shall be provided by giving the roadbed the same grade as that proposed for the gutter. The crown of all pavements shall not be more than one-one-hundredth (1/100) of the width, except when deemed advisable by the engineer—the crown of a pavement built on a crowned sub-grade may be increased to one-fiftieth (1/50) of the width to provide sufficient fall for drainage along the sides of the pavement at the curb.

VII. JOINTS.

Joints.

26. *Width and Location.*—Transverse joints shall be not less than one-quarter ($\frac{1}{4}$) inch nor more than three-eighths ($\frac{3}{8}$) inch in width, and shall be placed across the pavement perpendicular to the center line, not more than thirty-five (35) feet apart. A longitudinal joint, not less than one-quarter ($\frac{1}{4}$) inch wide shall be constructed between the curb and the pavement. All joints shall extend through the entire thickness of the pavement, and shall be perpendicular to its surface.

27. *Protection of Joints.*—The concrete at transverse joints shall be protected with soft steel joint protection plates which shall be rigidly anchored to the concrete. The type and installation of the metal protection plates shall meet with the approval of the engineer. The surface edges of the metal plates shall conform to the finished surface of the concrete, as shown in Fig. 1.

All joints over one-quarter ($\frac{1}{4}$) inch high or one-half ($\frac{1}{2}$) inch low, shall be removed.

28. *Joint Filler.*—All joints shall be formed by inserting during construction and leaving in place the required thickness of joint filler which shall extend through the entire thickness of the pavement.

VIII. MEASURING MATERIALS AND MIXING CONCRETE.

29. *Measuring.*—The method of measuring the materials for the concrete, including water, shall be one which will insure separate and uniform proportions of each of the materials at all times. A bag of Portland cement (94 lbs. net) shall be considered one (1) cubic foot. **Measuring Materials.**

30. *Mixing.*—The materials shall be mixed to the desired consistency in a batch mixer of approved type, and mixing shall continue for at least forty-five (45) seconds after all materials are in the drum. The drum shall be completely emptied before mixing successive batches. The drum of the mixer used shall revolve at a speed not less than the minimum nor more than the maximum number of revolutions shown in the following table: **Mixing.**

Rated Capacity, cu. ft. Unmixed Material.	Capacity, Bags of Cement in 1 : 2 : 3 mix.	Revolutions per Minute of Drum. Min.	Max.
7 to 11	1	15	21
12 to 17	2	12	20
18 to 23	3	12	20
24 to 29	4	11	17
30 to 33	5	10	15

31. *Retempering* of mortar or concrete which has partially hardened, that is, mixing with additional materials or water, shall not be permitted. **Retempering.**

32. *Proportions.*—The concrete shall be mixed in the proportions of one (1) bag of Portland cement to not more than two (2) cubic feet of fine aggregate and not more than three (3) cubic feet of coarse aggregate, and in no case shall the volume of the fine aggregate be less than one-half ($\frac{1}{2}$) the volume of the coarse aggregate. **Proportions.**

A cubic yard of concrete in place between neat lines shall contain not less than one and seven-tenths (1.7) barrels of cement.

The engineer shall compare the calculated amount of cement required according to these specifications and plans attached hereto with the amounts actually used in each section of concrete, between successive transverse joints, as determined by actual count of the number of bags of cement used in each section. If the amount of cement used in any three adjacent sections (between transverse joints) is less by two per cent, or if the

amount of cement used in any one section is less by five per cent than the amount hereinbefore specified, the contractor agrees to remove all such sections and to rebuild the same according to these specifications, at his expense.

Consistency.

33. *Consistency.*—The materials shall be mixed with sufficient water to produce a concrete which when deposited will settle to a flattened mass, but shall not be so wet as to cause a separation of the mortar from the coarse aggregate in handling.

IX. REINFORCING.

Reinforcing.

34. *Reinforcing.*—Concrete pavements twenty (20) feet or more in width shall be reinforced. The cross-sectional area of the reinforcing metal running parallel to the center line of the pavement shall amount to at least 0.038 square inch per foot of pavement width and the cross-sectional area of reinforcing metal, which is perpendicular to the center line of the pavement, shall amount to at least 0.049 square inch per foot of pavement length.

Reinforcing metal shall not be placed less than two (2) inches from the finished surface of the pavement and otherwise shall be placed as shown on the drawings. The reinforcing metal shall extend to within two (2) inches of all joints, but shall not cross them. Adjacent widths of fabric shall be lapped not less than four (4) inches.

X. PLACING CONCRETE.

Placing Concrete.

35. *Placing.*—Immediately prior to placing the concrete, the sub-grade shall be brought to an even surface. The surface of the sub-grade shall be thoroughly wet when the concrete is placed.

After mixing, the concrete shall be deposited rapidly in successive batches upon the sub-grade, prepared as hereinbefore specified. The concrete shall be deposited to the required depth and for the entire width of the pavement, in a continuous operation, between transverse joints, without the use of intermediate forms or bulkheads.

In case of a breakdown, concrete shall be mixed by hand to complete the section or an intermediate transverse joint placed as hereinbefore specified at the point of stopping work. Any

concrete in excess of that needed to complete a section at the stopping of work shall not be used in the work.

36. *Finishing.*—The surface of the concrete shall be struck off by means of a template or strike board, which shall be moved longitudinally or crosswise of the pavement. Concrete adjoining the metal protection plates at transverse joints shall be dense in character, and any holes left by removing any device used in installing the metal protection plates shall be immediately filled with concrete.

After being brought to the established grade with the template or strike board, the concrete shall be finished from a suitable bridge, no part of which shall come in contact with the concrete. The concrete shall be finished with a wood float in a manner to thoroughly compact it and produce a surface free from depressions or inequalities of any kind. The finished surface of the pavement shall not vary more than one-quarter ($\frac{1}{4}$) inch from the true shape.

XI. PROTECTION.

37. *Curing and Protection.*—Excepting as hereinafter specified, the surface of the pavement shall be sprayed with water as soon as the concrete is sufficiently hardened to prevent pitting, and shall be kept wet until an earth covering is placed. As soon as it can be done without damaging the concrete, the surface of the pavement shall be covered with not less than two (2) inches of earth or other material which will afford equally as good protection, which cover shall be kept moist for at least ten (10) days. When deemed necessary or advisable by the engineer, freshly laid concrete shall be protected by a canvas covering until the earth covering can be placed. Protection.

Under the most favorable conditions for hardening in hot weather the pavement shall be closed to traffic for a least fourteen (14) days, and in cool weather for an additional time, to be determined by the engineer.

If at the time the pavement is laid or during the period of curing the temperature during the daytime drops below 50 degrees Fahrenheit, sprinkling and covering of the pavement shall be omitted at the direction of the engineer.

The contractor shall erect and maintain suitable barriers to

protect the concrete from traffic and any part of the pavement damaged from traffic or other causes, occurring prior to its official acceptance, shall be repaired or replaced by the contractor at his expense, in a manner satisfactory to the engineer. Before the pavement is thrown open to traffic the covering shall be removed and disposed of as directed by the engineer.

Freezing.

38. *Temperature Below 35 Degrees Fahrenheit.*—Concrete freezing shall not be mixed or deposited when the temperature is below freezing.

If at any time during the progress of the work the temperature is, or in the opinion of the engineer will, within twenty-four (24) hours drop to 35 degrees Fahrenheit, the water and aggregates shall be heated, and precautions taken to protect the work from freezing for at least ten (10) days. In no case shall concrete be deposited upon a frozen sub-grade.

XII. SHOULDERS.

Shoulders.

39. *Construction.*—When shoulders are required, they shall be built upon the properly prepared sub-grade, as shown on the cross-sectional drawing, Fig. 1. The work shall be done to the entire satisfaction of the engineer.

AMERICAN CONCRETE INSTITUTE

Founded 1905 and Incorporated 1906, as
NATIONAL ASSOCIATION OF CEMENT USERS
Charter Amended July 2, 1913.

PHILADELPHIA, PA.

PROPOSED STANDARD SPECIFICATIONS FOR TWO COURSE CONCRETE STREET PAVEMENT.

I. MATERIALS.

1. The *cement* shall meet the requirements of the Standard Specifications for Portland Cement, adopted by the American Society for Testing Materials, August 16, 1909, with all subsequent amendments and additions thereto, adopted by said Society and adopted by this Institute (Standard No. 1). **Cement.**

When the cement is not inspected at the place of manufacture it shall be stored a sufficient length of time to permit of inspecting and testing. The engineer shall be notified of the receipt of each shipment of cement.

2. *Fine aggregate* shall consist of sand or screenings from clean, hard, durable, crushed rock or gravel consisting of quartzite grains or other equally hard material graded from fine to coarse, with the coarse particles predominating and passing, when dry, a screen having $\frac{1}{4}$-inch openings. It shall be clean, hard, free from dust, loam, vegetable, or other deleterious matter. Not more than twenty (20) per cent shall pass a sieve having fifty (50) meshes per linear inch, and not more than five (5) per cent shall pass a sieve having one hundred (100) meshes per linear inch. **Aggregate.**

Fine aggregate containing more than three (3) per cent of clay or loam shall be washed before using.

Fine aggregate shall be of such quality that the mortar composed of one (1) part Portland cement and three (3) parts fine aggregate by weight, when made into briquettes, shall show a tensile strength at least equal to the strength of 1 to 3 mortar of the same consistency made with the same cement and Standard Ottawa sand.

In no case shall fine aggregate containing frost or lumps of frozen material be used.

3. *Coarse aggregate* shall consist of clean, hard, durable, crushed rock or gravel, graded in size, free from dust, loam, vegetable or other deleterious matter and shall contain no soft, flat or elongated particles. The size of the coarse aggregate shall be such as to pass a one and one-half ($1\frac{1}{2}$) inch round opening and be retained on a screen having one-quarter ($\frac{1}{4}$) inch openings. In no case shall coarse aggregate containing frost or lumps of frozen material be used.

4. *Aggregate for the wearing course* shall consist of a mixture of two (2) parts of the materials specified under *Fine Aggregate*, and three (3) parts of clean, hard, durable, crushed rock or gravel, free from dust, soft particles, loam, vegetable or other deleterious matter, and passing when dry a screen having one-half ($\frac{1}{2}$) inch openings and retained on a screen having one-quarter ($\frac{1}{4}$) inch openings. In no case shall aggregate for wearing course containing frost or lumps of frozen material be used.

5. *Natural mixed aggregate* shall not be used as it comes from deposits, but shall be screened, and used as specified.

6. *Water* shall be clean, free from oil, acid, alkali or vegetable matter.

forcement. 7. *Reinforcement.*—Concrete pavements twenty (20) feet or more in width shall be reinforced with metal fabric. All reinforcement shall be free from excessive rust, scale, paint or coatings of any character which will tend to destroy the bond. All reinforcement shall develop an ultimate tensile strength of not less than 70,000 pounds per square inch and bend 180 deg. around one diameter and straighten without fracture.

Filler. 8. *Joint Filler* shall consist of prepared felt or similar material of approved quality having a thickness of not less than $\frac{1}{8}$ nor more than $\frac{1}{4}$ in.

Protection 9. *Joint Protection Plates.*—Soft steel plates for the protection of the edges of the concrete at transverse joints shall be not less than $2\frac{1}{2}$ in. in depth and not less than $\frac{1}{8}$ in. at any point nor more than $\frac{1}{4}$ in. in average thickness. The plates shall be of such form as to provide for rigid anchorage to the concrete. The type and method of installation of joint protection plates shall be approved by the engineer.

10. *Shoulders.*—Materials for the construction of shoulders shall be approved by the engineer. **Shoulders.**

II. GRADING.

11. *Defined.*—The term "grading" shall include all cuts, fills, approaches and all earth moving for whatever purpose where such work is an essential part of or necessary to the prosecution of the contract. When to bring the surface to grade, a fill of one (1) foot or less is required, the area shall be thoroughly grubbed. All soft, spongy or yielding spots and all vegetable or other objectionable matter shall be removed and the space refilled with suitable material. **Defined.**

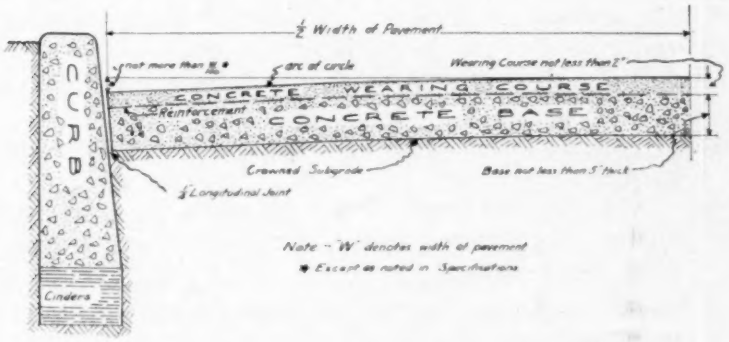


FIG. 1.—TWO COURSE CONCRETE PAVEMENT FOR PAVEMENT OVER 20 FT. WIDE.

12. *Stakes* will be set by the engineer for center line side of slopes, finished grade and other necessary points properly marked for the cut or fill. **Engineer's Stakes.**

13. *Excess material* shall be disposed of as directed by the engineer, the free haul not to exceed.....feet. **Excess Material.**

14. *Over-haul.*—Materials hauled a greater distance than the free haul from the place of excavation shall be paid for at the rate of.....cents per cubic yard for each additional..... feet.

15. *Fills.*—Embankments shall be formed of earth or other approved materials and shall be constructed in successive layers, the first of which shall extend entirely across from the toe of the slope on one side to the toe of the slope on the other side, and **Fills.**

successive layers shall extend entirely across the embankments from slope to slope. Each layer which shall not exceed one foot in depth, shall be thoroughly rolled with a roller weighing not less than five (5) tons nor more than ten (10) tons before the succeeding layer is placed. The roller shall pass over the entire area of the fill at least twice.

The sides of the embankment shall be kept lower than the center during all stages of the work and the surface maintained in condition for adequate drainage. The use of muck, quicksand, soft clay or spongy material which will not consolidate under the roller is prohibited.

When the material excavated from the cuts is not sufficient to make the fills shown on the plans the contractor shall furnish the necessary extra material to bring the fills to the proper width and grade. When the earth work is completed the cross-section of the road shall conform to the cross-sectional drawings and profile shown in Fig. 1.

Slopes.

16. All *slopes* must be properly dressed to lines given by the engineer.

Finished Grade.

17. *Finished Grade.*—When the grade line is approached the final grade stakes will be set, for which sufficient notice must be given to the engineer.

NOTE.—In excavating cuts it is considered advisable when the line of the sub-grade is approached, to compact the remaining material by rolling. The depth of material left in the cut to be compressed to the finished grade by rolling will depend upon the character of the material.

III. DRAINAGE.

Drainage.

18. *Drainage.*—The contractor shall construct tile or other drains as shown in the drawings attached hereto. Tile to be laid in the trench at least.....(.....) inches wide and.....(.....) feet deep below the top of the adjacent curb. Such trench shall be back filled with crushed stone or pit run gravel with sand removed, which after light tamping shall be.....(.....) inches in depth.

19. *Catch Basins.*—All catch basins and manhole tops and all covers of openings of any kind shall be readjusted to the grade by the contractor at his expense.

IV. SUB-GRADE.

Sub-Grade.

20. *Construction.*—The bottom of the excavation or the top of the fill, when completed, shall be known as the sub-grade and shall be at all places true to the elevation as shown on the plans attached hereto.

The street shall be graded from curb to curb to the proper sub-grade to permit of specified thickness of paving materials being laid to bring the finished surface of the pavement to the lines and grades as shown on the plans. The sub-grade shall be brought to a firm, unyielding surface by rolling the entire area with a self-propelled roller weighing not less than ten (10) tons, and all portions of the surface of the sub-grade which are inaccessible to the roller shall be thoroughly tamped with a hand tamp weighing not less than fifty (50) pounds, the face of which shall not exceed 100 square inches in area. All soft, spongy or yielding spots and all vegetable or other objectionable matter shall be entirely removed and the space refilled with suitable material.

Where considered necessary, or of assistance in producing a compact solid surface, the subgrade, before being rolled, shall be well sprinkled with water.

When the concrete pavement is to be constructed over an old roadbed composed of gravel or macadam, and the concrete is to be wider than the old gravel or macadam road, the latter shall be entirely loosened and the material spread for the full width of the roadbed and rolled. All interstices shall be filled with fine material, and rolled to make a dense, tight surface of the roadbed.

21. *Acceptance.*—No concrete shall be deposited upon the subgrade until it is checked and accepted by the engineer.

22. *Completion.*—Upon the subgrade thus formed shall be laid the concrete pavement as shown in Fig. 1.

V. FORMS.

Forms

23. *Materials.*—The forms when required shall be free from warp, of sufficient strength to resist springing out of shape, and shall be equal in width to the thickness of the pavement at the edges. Wooden forms shall be of not less than two (2) inch stock, and shall be capped with two (2) inch angle iron.

24. *Setting.*—The forms shall be well staked or otherwise

held to the established line and grades, and the upper edges shall conform to the established grade of the street.

25. *Treatment.*—All mortar and dirt shall be removed from the forms that have previously been used.

VI. PAVEMENT SECTION.

Pavement Sections.

26. *Width, Thickness of Concrete and Crown.*—The concrete pavement shall be.....(.....) feet wide from face to face of curb. The base of the concrete pavement shall be.....(.....) inches in depth at the center and.....(.....) inches in depth at the sides. The wearing course shall be of..... (.....) inches uniform thickness. The finished surface shall conform to the arc of a circle as shown in Fig. 1.

NOTE.—The minimum thickness of the concrete base shall be not less than five (5) inches and the minimum thickness of the wearing course shall be not less than two (2) inches. When pavements twenty (20) feet or less in width are to be built on approximately level ground and a flat sub-grade is to be used, sufficient fall for drainage at the sides of the pavement along the curb shall be provided by giving the roadbed the same grade as that proposed for the gutter. The crown of all pavements shall not be more than one-one-hundredth (1/100) of the width except, when deemed advisable by the engineer, the crown of a pavement built on a crowned sub-grade may be increased to one-fiftieth (1/50) of the width to provide sufficient fall for drainage along the sides of the pavement at the curb.

VII. JOINTS.

Joints.

27. *Width and Location.*—Transverse joints shall be not less than one-quarter ($\frac{1}{4}$) inch nor more than three-eighths ($\frac{3}{8}$) inch in width and shall be placed across the pavement perpendicular to the center line, not more than thirty-five (35) feet apart. A longitudinal joint, not less than one-quarter ($\frac{1}{4}$) inch, shall be constructed between the curb and the pavement. All joints shall extend through the entire thickness of the pavement and shall be perpendicular to its surface.

28. *Protection of Joints.*—The concrete at transverse joints shall be protected with soft steel joint protection plates which shall be rigidly anchored to the concrete. The installation of the metal protection plates shall meet with the approval of the engineer.

The surface edges of the metal plates shall conform to the finished surface of the concrete, as shown in Fig. 1.

All joints over one-quarter ($\frac{1}{4}$) inch high or one-half ($\frac{1}{2}$) inch low shall be removed.

29. *Joint Filler.*—All joints shall be formed by inserting during construction and leaving in place the required thickness of joint filler which shall extend through the entire thickness of the pavement.

VIII. MEASURING MATERIALS AND MIXING CONCRETE.

Measuring Materials.

30. *Measuring.*—The method of measuring the materials for the concrete, including water, shall be one which will insure separate and uniform proportions of each of the materials at all times. A bag of Portland cement (94 pounds net) shall be considered one (1) cubic foot.

Mixing.

31. *Mixing.*—The materials shall be mixed to the desired consistency in a batch mixer of approved type and mixing shall continue for at least forty-five (45) seconds after all the materials are in the drum. The drum shall be completely emptied before mixing successive batches. The drum of the mixer used shall revolve at a speed not less than the minimum nor more than the maximum number of revolutions shown in the following tables:

Rated Capacity, cu. ft. Unmixed Material.	Capacity, Bags of Cement in 1 : 2 : 3 mix.	Revolutions per Minute of Drum. Min.	Max.
7 to 11	1	15	21
12 to 17	2	12	20
18 to 23	3	12	20
24 to 29	4	11	17
30 to 33	5	10	15

Retempering.

32. *Retempering* of mortar or concrete which has partially hardened, that is mixing with additional materials or water, shall not be permitted.

Consistency.

33. *Consistency.*—The materials shall be mixed with sufficient water to produce a concrete which when deposited will settle to a flattened mass but shall not be so wet as to cause a separation of the mortar from the coarse aggregate in handling.

Cement Required.

34. *Cement Required.*—A cubic yard of concrete base in place shall contain at least 1.4 barrels of cement and a cubic yard of wearing course in place shall contain at least 2.97 barrels of cement.

The engineer shall compare the calculated amount of cement required according to these specifications and plans attached hereto with the amounts actually used in each section of concrete between successive transverse joints, as determined by actual count of the number of bags of cement used in each section. If the amount of cement used in any three adjacent sections (between transverse joints) is less by two per cent, or if the amount of cement used in any one section is less by five per cent than the amount hereinbefore specified, the contractor agrees to remove all such sections and to rebuild the same according to these specifications, at his expense.

IX. REINFORCING.

Reinforcing.

35. Concrete pavements twenty (20) feet or more in width shall be reinforced. The cross-sectional area of the reinforcing metal running parallel to the center line of the pavement shall amount to at least 0.038 square inch per foot of pavement width and the cross-sectional area of reinforcing metal, which is perpendicular to the center line of the pavement, shall amount to at least 0.049 square inch per foot of pavement length.

Reinforcing metal shall be placed between base and wearing course and shall not be less than two (2) inches from the finished surface of the pavement and otherwise shall be placed as shown on the drawings. The reinforcing metal shall extend to within two (2) inches of all joints, but shall not cross them. Adjacent widths of fabric shall be lapped not less than four (4) inches.

X. PROPORTIONING AND PLACING CONCRETE.

A. CONCRETE FOR BASE.

Concrete for Base.

36. *Proportions.*—The concrete shall be mixed in the proportions of one (1) bag of Portland cement to not more than two and a half ($2\frac{1}{2}$) cubic feet of fine aggregate, and not more than four (4) cubic feet of coarse aggregate, and in no case shall the volume of the fine aggregate be less than one-half ($\frac{1}{2}$) the volume of the coarse aggregate.

37. *Placing.*—Immediately prior to placing the concrete, the sub-grade shall be brought to an even surface. The surface of the sub-grade shall be thoroughly wet when the concrete is placed.

After mixing, the concrete shall be deposited rapidly in successive batches upon the sub-grade prepared as hereinbefore specified. The concrete shall be deposited to the required depth and for the entire width of the pavement, in a continuous operation, between transverse joints, without the use of intermediate forms or bulkheads.

The concrete shall be brought to a comparatively even surface, the thickness of the wearing course below the established grade of the pavement. Workmen shall not be allowed to walk on the freshly laid concrete and if sand or dust collects on the base it shall be removed before the wearing course is applied. The reinforcing metal shall be placed upon and slightly pressed into the concrete base immediately after it is placed.

In case of a breakdown, concrete shall be mixed by hand to complete the section, or an intermediate transverse joint placed, as hereinbefore specified, at the point of stopping work. Any concrete in excess of that needed to complete a section, at the stopping of work, shall not be used in the work.

B. CONCRETE FOR WEARING COURSE.

Concrete for Wearing Course.

38. *Proportions.*—The mortar for the wearing course shall be mixed in the manner hereinbefore specified in the proportion of one (1) bag of Portland cement and not more than two (2) cubic feet of "Aggregate for Wearing Course" hereinbefore specified.

39. *Placing.*—The wearing course shall be placed immediately after mixing and in no case shall more than forty-five (45) minutes elapse between the time that the concrete for the base has been mixed and the time the wearing course is placed.

40. *Finishing.*—The wearing course shall be struck off by means of a template or strike board, which shall be moved longitudinally or crosswise of the pavement. Concrete adjoining the metal protection plates at transverse joints shall be dense in character and any holes left by removing any device used in installing the metal protection plates shall be immediately filled with a mortar composed of one (1) part Portland cement to not more than two (2) parts of fine aggregate.

After being brought to an established grade with the template or strike board, the concrete shall be finished from a suitable

bridge, no part of which shall come in contact with the concrete. The concrete shall be finished with a wood float in a manner to thoroughly compact it, and produce a surface free from depressions or inequalities of any kind. The finished surface of the pavement shall not vary more than one-quarter ($\frac{1}{4}$) inch from the true shape.

XI. PROTECTION.

Protection.

41. *Curing and Protection.*—Excepting as hereinafter specified, the surface of the pavement shall be sprayed with water as soon as the concrete is sufficiently hardened to prevent pitting, and shall be kept wet until an earth covering is placed. As soon as it can be done without damaging the concrete, the surface of the pavement shall be covered with not less than two (2) inches of earth or other material which will afford equally as good protection, which cover shall be kept moist for at least ten (10) days. When deemed necessary or advisable by the engineer freshly laid concrete shall be protected by a canvas covering until the earth covering can be placed.

If at the time the pavement is laid, or during the period of curing, the temperature during the daytime drops below 50 degrees Fahrenheit, sprinkling and covering of the pavement shall be omitted at the direction of the engineer.

Under the most favorable conditions for hardening, in hot weather, the pavement shall be closed to traffic for at least fourteen (14) days, and in cool weather for an additional time to be determined by the engineer.

The contractor shall erect and maintain suitable barriers to protect the concrete from traffic, and any part of the pavement damaged from traffic or other causes occurring prior to its official acceptance, shall be repaired or replaced by the contractor, at his expense, in a manner satisfactory to the engineer. Before the pavement is thrown open to traffic the covering shall be removed and disposed of as directed by the engineer.

42. *Temperature Below 35 Degrees Fahrenheit.*—If at any time during the progress of the work the temperature is, or in the opinion of the engineer will within twenty-four (24) hours drop to 35 degrees Fahrenheit, the water and aggregates shall be heated and precautions taken to protect the work from freezing for at

least ten (10) days. In no case shall concrete be deposited upon a frozen sub-grade.

XII. SHOULDERS.

43. *Construction.*—When shoulders are required they shall be built up on the properly prepared sub-grade, as shown on the cross-sectional drawing, Fig. 1. The work shall be done to the entire satisfaction of the engineer. Shoulders.

AMERICAN CONCRETE INSTITUTE

Founded 1905 and Incorporated 1906, as
NATIONAL ASSOCIATION OF CEMENT USERS
Charter Amended July 2, 1913.

PHILADELPHIA, PA.

PROPOSED REVISED STANDARD SPECIFICATIONS FOR PORTLAND CEMENT STUCCO ON METAL LATH, BRICK, TILE OR CONCRETE BLOCK.

Paragraphs marked (a) apply only to back-plastered walls without sheathing.
Paragraphs marked (b) apply only to walls with sheathing.
All other paragraphs apply to both forms of construction.

MATERIALS.

1. *Cement.*—The cement shall meet the requirements of the Standard Specifications for Portland Cement of the American Society for Testing Materials, and adopted by this Institute (Standard No. 1).

2. *Fine Aggregate* shall consist of sand, crushed stone, or gravel screenings, graded from fine to coarse, passing when dry a screen having ¼ in. diameter holes, shall be preferably of silicious materials, clean, coarse, free from loam, vegetable or other deleterious matter.

3. *Lime.*—The lime shall be thoroughly hydrated either by the manufacturer, or the contractor. If hydrated by the contractor, it shall be slaked in sufficient water to make a soft paste and allowed to stand at least one week before being applied to the wall.

4. *Hair or Fibre.*—There shall be used only first quality long hair, free from foreign matter, or a long fibre well combed out.

5. *Coloring Matter.*—Only inorganic colors shall be used which are not affected by lime, Portland cement, other ingredients of the mortar, or the weather.

6. *Water* shall be clean, free from oil, acid, strong alkalies or vegetable matter.

PREPARATION OF MORTAR.

7. *Mixing.*—The ingredients of the mortar shall be thoroughly mixed to a uniform color, sufficient water added to obtain the desired consistency, and the mixing shall continue until the cement and lime are uniformly distributed and the mass is uniform in color and homogeneous.

The hair or fibre shall be added during the process of wet mixing.

8. *Measuring Proportions.*—Methods of measurement of the proportions of the various ingredients, including the water, shall be used which will secure separate uniform measurements at all times. All proportions stated are by volume. A bag of cement (94 lb. net) shall be assumed to contain 1 cu. ft. Lime when used shall be measured in the form of putty. Hydrated lime shall be made into putty before being measured.

9. *Quantity.*—There shall not be mixed at one time more mortar than will be used within one hour. Mortar which has begun to stiffen or take on its initial set shall not be used.

10. *Hand Mixing.*—The mixing shall be done on a water-tight platform and the materials shall be turned until they are homogeneous in appearance and color.

11. *Consistency.*—The materials shall be mixed so as to provide sufficient water to insure a proper bonding and a dense mortar free from voids.

12. *Retempering.*—Retempering mortar, *i. e.*, remixing with water after it has partially set, shall not be allowed.

STRUCTURE.

13. *Framing.*—Studs spaced at 12-in. centers wherever possible shall be run from foundation to rafters without any intervening horizontal grain in the wood. These studs shall be tied together just below the floor joists by 6-in. boards which will be let into the studs on their inner side, so as to be flush and securely nailed to them. These boards will also act as sills for the floor joists, which in addition will be securely spiked to the side of the studs.

14. *Bracing.*—The frame of the building shall be so rigidly constructed and braced as to avoid cracking the stucco.

(*a*) At least once between each two floors, brace between the studding with 2 x 3 in. bridging.

(*b*) Bracing may be omitted, as the sheathing boards act as bracing.

15. *Sheathing.*—(*a*) The lath is to be fastened direct to the studding and back-plastered and no sheathing boards are to be used.

(*b*) Sheathing boards shall be not less than 6 in. or more than 8 in. wide, dressed on one or both sides to a uniform thickness of $\frac{7}{8}$ in. They shall be laid diagonally across the wall studs and fastened with two nails at each stud.

16. *Inside Waterproofing.*—(*a*) The faces of the studs and for one inch back of the face on each side where the plaster may come in contact with them, shall be thoroughly waterproofed with tar or asphalt.

(*b*) Over the sheathing boards shall be laid in horizontal layers, beginning at the bottom, a substantial paper well impregnated and thoroughly waterproofed with tar or asphalt. The bottom strip shall lap over the base board at the bottom of the wall, and each strip shall lap the one below at least 2 in. The paper shall lap the flashings at all openings. When required, the lower horizontal edge of each strip shall be cemented with hot or liquid tar or asphalt compound, to the strip below and to the grounds of flashings at all openings. All tacking shall be within 2 in. of the top horizontal edge, where tacks will be covered by the lap of the strip above.

17. *Furring.*—When furring forms a part of the metal lath to be used, then separate furring as described in this paragraph is to be omitted.

(*a*) Galvanized or painted $\frac{1}{2}$-in. crimped furring, not lighter than 22 gauge or other shape giving equal results, shall be fastened direct to the studding, using $1\frac{1}{4}$-in. x 14 gauge staples, placed 12 in. apart.

(*b*) Galvanized or painted $\frac{1}{2}$-in. crimped furring, not lighter than 22 gauge or other shape giving equal results, shall be fastened over the sheathing paper and directly along the line of the studs, using $1\frac{1}{4}$-in. x 14 gauge staples, placed 12 in. apart. The same depth of furring should be adhered to around curved sur-

faces, and furring shall be placed not less than 1½ in. or more than 4 in. on each side of and above and below all openings.

18. *Preparation of Original Surface.*—All roof gutters shall be fixed and down-spout hangers and all other fixed supports and fasteners shall be put up before the plastering is done, so there will be no break made in the plastering where they are permanently fixed.

Wall copings, balustrade rails, chimney caps, cornices, etc., shall be built of concrete, stone, tile or metal with ample overhang drip grooves or lip, and water tight joints, to keep water from behind the plaster.

If wood sills are used, they should project well from the face of the plaster and have ample drip groove or lip.

Metal lath shall be stopped far enough above the level of the ground to be free from ground moisture.

Care should be taken to provide for placing all trim the proper distance from the studding or furring to show its right projection after the plaster is on.

19. *Lath.*—The lath shall be not thinner than 24 gauge, galvanized or painted, expanded metal lath weighing not less than 3¼ lbs. to the square yard, or woven wire lath, galvanized or painted, 19 gauge 2½ meshes to the inch with stiffeners at 8-in. centers.

20. *Application of Lath.*—Place lath horizontally over the furring driving galvanized staples 1¼-in. x 14 gauge 8 in. apart over the furring into the studding. The sheets of lath shall be locked or lapped at least 1 in. and tied at joints between studs both vertically and horizontally with 18 gauge wire.

21. *Corners.*—There shall be 6-in. strips of metal lath bent around the corners and stapled over the lath, or the sheets of metal lath shall be folded around the corners a distance of at least 3 in. and stapled down, as applied. Galvanized corner bead may be applied over the lath.

22. *Insulation.*—(*a*) After the lath on the outside has been back-plastered, the air space may be divided by applying heavy building paper, quilting, felt or other suitable insulating material between the studs, fastening it to the studs by nailing wood strips over folded ends of the material. This insulation should be so fastened as to clear the bridging, leaving the preponderance

of the air space next to the plaster. Care must be taken to keep the insulating material clear of the outside plaster and to make tight joints against the wood framing at the top and bottom of the spaces and against the bridging where the face intercepts.

(*b*) When quilting, felt, or other insulating material is to be used it shall be applied to the sheathing boards under the inside waterproofing.

23. *Brick, Tile or Cement Block Surfaces.—Existing surfaces* to be stuccoed shall have all loose, friable or soft mortar removed from the joints to a depth of not less than ½ in. All dirt, dust or any other foreign matter shall be removed by means of a wire brush, stiff broom or other effective means. In case the surface has been painted, is oily or otherwise in such condition that the stucco will not firmly adhere, then metal furring and lathing shall first be applied.

New surfaces shall have ample roughness to assure a strong bond and key between the stucco and the surface. The mortar joints shall not be less than ⅜ in. thick and the mortar shall be omitted from or raked out of the joints for at least ½ in. back from the face to which the stucco is applied. Before placing the scratch coat the surface shall be brushed clean from all dust, dirt or loose particles and thoroughly wetted, and shall be in this condition when the plaster is applied.

MORTAR COATS.

24. *Plaster.*—(*a*) The *first coat* shall contain not more than two and one-half (2½) parts of sand to one (1) part of Portland cement by volume. If lime putty is added, it shall not be in excess of one-third (⅓) of the volume of cement. Hair or fibre may be added in sufficient quantity to bond the mortar.

(*b*) The *first coat* shall contain not more than two and one-half (2½) parts of sand to one (1) part of Portland cement by volume. If lime putty is added it shall not be in excess of one-third (⅓) of the volume of cement. No hair, fibre or similar material of any kind or in any quantity shall be added to the mortar.

For *second coat*, the proportion of sand to cement shall not be greater than 2½ to 1 by volume, nor shall more than ⅓ part of lime putty be added.

For *third coat*, the proportion of sand to cement shall not be

less than 2 to 1 nor more than 2½ to 1, by volume, nor shall more than ⅓ part of lime putty be added.

25. *Application.*—The plastering should be carried on continuously in one general direction, without allowing the plaster to dry at the edge. If it is impossible to work the full width of the wall at one time, the joint should be at some natural division of the surface, such as a window or door.

Metal Lath.—(*a*) The first coat shall be applied to the outside of the lath and pushed through sufficiently to give a good key. Over the face of the studs the plaster shall be forced well through the lath in order to fill entirely the space between the lath and the stud. The backing coat shall be applied to the back of the lath and shall be thoroughly troweled so that the lath shall be entirely covered. The final coat shall be applied to the face of the first coat.

(*b*) The first coat shall be applied to the lath and thoroughly pushed through against the inside waterproofing so as to completely embed the metal of the lath on both sides. Special care shall be taken to fill all voids around furring strips and where laths lap.

Brick, Tile or Cement Block Surfaces.— The first coat shall be forcibly and thoroughly troweled into the depressions of the previously saturated surface so as to make a firm bond. Care shall be taken to insure the complete filling by the mortar of all crevices and pores.

If subsequent coats are applied they shall be well troweled to insure good bond with the previous coat.

26. *Roughing.*—Soon after applying and before the initial set has taken place, the surface of the coats which are to receive succeeding coats shall be roughened with a saw-toothed paddle or other suitable device.

27. *Dampening.*—Before applying mortar the surface of the preceding coat shall be thoroughly wetted to prevent absorption of water from the fresh mortar.

28. *Thickness of Coats.*—(*a*) The first coat shall be at least ¾ in. thick over the face of the lath and project through behind the lath about ⅜ in. The backing coat shall increase the thickness behind the lath to not less than ⅝ in. The final coat shall be not less than ⅜ in. thick.

(*b*) The first coat shall have a minimum thickness over the lath at any point of not less than $\frac{1}{4}$ in. The intermediate coat shall have a thickness of not less than $\frac{1}{4}$ in. or more than $\frac{3}{8}$ in. The final coat shall have a thickness of $\frac{1}{4}$ in. when placed over an intermediate coat, or of $\frac{3}{8}$ in. when placed directly on the scratch coat.

29. *Drying Out.*—The final coat shall not be permitted to dry out rapidly and adequate precaution shall be taken, either by sprinkling frequently after the mortar has set hard enough to permit it or by hanging wet burlap or other material over the surface.

30. *Freezing.*—Stucco should never be applied when the temperature is below freezing.

FINISH.

31. *Smooth Troweled.*—The finishing coat shall be troweled smooth with a metal trowel with as little rubbing as possible.

32. *Stippled.*—The finishing coat shall be troweled smooth with a metal trowel with as little rubbing as possible, and then shall be lightly patted with a brush of broom straw to give an even, stippled surface.

33. *Sand Floated.*—The finishing coat, after being brought to a smooth, even surface, shall be rubbed with a circular motion of a wood float with the addition of a little sand to slightly roughen the surface. This floating shall be done when the mortar has partially set.

34. *Sand Sprayed.*—After the finishing coat has been brought to an even surface, it shall be sprayed by means of a wide, long fibre brush—a whisk-broom does very well—dipped into a creamy mixture of equal parts of cement and sand, mixed fresh every 30 minutes and kept well stirred in the bucket by means of the whisk-broom or a paddle. This coating shall be thrown forcibly against the surface to be finished. This treatment shall be applied while the finishing coat is still moist and before it has attained its final set, *i.e.*, within 3 to 5 hours. To obtain lighter shades add hydrated lime of 5 to 15 per cent. of the volume of the cement.

35. *Splatter Dash or Rough Cast.*—After the finishing coat has been brought to a smooth, even surface and before attaining

final set, it shall be uniformly coated with a mixture of one part cement and two parts of sand thrown forcibly against it to produce a rough surface of uniform texture when viewed from a distance of 20 ft. Special care shall be taken to prevent the rapid drying out of this finish.

36. *Pebble Dash.*—After the finishing coat has been brought to a smooth, even surface, and before attaining initial set, clean round pebbles or other material as selected, not smaller than $\frac{1}{4}$ in. or larger than $\frac{3}{4}$ in., previously wetted, shall be thrown forcibly against the mortar so as to embed themselves in the fresh mortar. They shall be distributed uniformly over the surface of the final coat and may be pushed back into the mortar with a clean wood trowel, but no rubbing of the surface shall be done after the pebbles are embedded.

37. *Exposed Aggregates.*—The finishing coat shall be composed of an approved, selected coarse sand, marble dust, granite dust or other special material, in the proportion given for finishing coats and within 24 hours after being applied and troweled to an even surface, shall be scrubbed with a stiff brush and water. In case the cement is too hard a solution of one part hydrochloric acid in four parts of water by volume can be used in place of water. After the aggregate particles have been uniformly exposed by scrubbing, particular care shall be taken to remove all traces of the acid by thorough spraying with a hose.

38. *Mortar Colors.*—When it is required that any of the above finishes shall be made with colored mortar, not more than 6 per cent. of the weight of Portland cement shall be added to the mortar in the form of finely ground coloring matter.

A predetermined weight of color shall be added dry to each batch of dry fine aggregate before the cement is added. The color and fine aggregate shall be mixed together and then the cement mixed in. The whole shall then be thoroughly mixed dry by shoveling from one pile to another through a $\frac{1}{4}$-in. mesh wire screen until the entire batch is of uniform color. Lime putty, if used, and water shall then be added to bring the mortar to a proper plastering consistency.

Machine Stucco.

39. Stucco may be applied by a machine provided the results obtained are equal to those produced by hand work.

OVERCOATING.

During recent years there has come into vogue a method of remodeling old frame houses. This "overcoating", as it is called, is used extensively in all sections of the country and the following practice is recommended:

40. Where furring is used so deep that the space back of the lath is not entirely filled with plaster, some provision must be made for extending the old window and door frames to correspond with the increased thickness of the wall. In some cases the plaster is brought over the old frames in such a manner that a recessed window or door opening is made. In case the furring is fastened to the studding, it is not necessary to provide for extending the window and door frames, as the new stucco finish will have the same relations as the old weather-boarding.

41. *Preparation of Original Surface.*—If the weather-boarding is in poor condition it should be removed and furring and metal lath applied over the sheathing, to which waterproof paper has previously been fastened. It may be advisable also to tear off the sheating, in which case the furring can be fastened direct to the studding after bracing between the studs.

Another method would be to fasten the furring direct over the weather-boarding over which the metal lath is applied.

In preparation for any of these methods the house should be gone over carefully to determine if the framework is well enough preserved to justify the improvement.

The doors should be looked after, the studding inspected, partitions and outside walls lined up and brought into plumb.

42. *Furring.*—Fasten galvanized or painted ½-in. crimped furring or other shape giving equal results, vertically over the original surface, whichever of the above may be adopted.

43. *Lathing and Plastering.*—Follow the above specifications for stucco.

INSTITUTE NOTES.

Standards Adopted by the Institute.

1. Standard Specifications for Cement with Appendix on Standard Methods of Testing and Chemical Analysis, 23 pp.
2. Standard Specifications for Portland Cement Sidewalks, 6 pp.
4. Standard Building Regulations for the Use of Reinforced Concrete, 13 pp.
5. Standard Specifications for One Course Concrete Highway, 10 pp.
6. Standard Specifications for Portland Cement Curb and Gutter, 7 pp.
7. Standard Recommended Practice for the Use of Reinforced Concrete, 21 pp.
8. Standard Specifications for Scrubbed Concrete Surfaces, 3 pp.
9. Standard Recommended Practice for Concrete Drain Tile, 3 pp.
10. Standard Recommended Practice for Concrete Architectural Stone, Building Block and Brick, 4 pp.
11. Standard Specifications for Concrete Architectural Stone, Building Block and Brick, 3 pp.
12. Standard Building Regulations for the Use of Concrete Architectural Stone, Building Block and Brick, 3 pp.
13. Standard Specifications for Plain Concrete Floors, 6 pp.
14. Standard Specifications for Reinforced Concrete Floors, 5 pp.
15. Standard Specifications for Portland Cement Stucco on Metal Lath, Brick, Tile or Concrete Block, 9 pp.
16. Standard Methods for the Measurement of Concrete Work, 7 pp.
17. Standard Specifications for One Course Concrete Street Pavement, 10 pp.
18. Standard Specifications for Two Course Concrete Street Pavement, 11 pp.

The above Standards can be obtained at the price of 25 cents each or in lots of ten or more at 20 cents each. Special price to Members 15 cents each or 10 cents each in lots of ten.

Reduced Price for Back Volumes.

Members of the Institute can obtain copies of back publications at the following special prices:

Vol. I, 50 cents; Vols. II to VI, $1.50 each; all in paper binding. For cloth or half morocco binding there is an additional charge per volume of 50 cents or $1.00 respectively. Vol. VII is available only in cloth binding, $2.00, or half morocco, $2.50.

New Members

In order that the excellent work of the Institute may in its benefit be as far reaching as possible, it behooves every member of the Institute to interest others in this work so that the Institute may serve them and receive their co-operation. Each issue of the Journal will contain an application blank for membership, and it is hoped that each blank will be put to good use by the members. Special information as to the work of the Institute will be gladly supplied by the Secretary, who will also be pleased to communicate with prospective members.

SYNOPSIS OF RECENT ARTICLES ON CONCRETE.

Reviewed October 1 to 31, 1914.

The synopses given below are for the purpose of keeping the members of the Institute in touch with the leading articles of interest appearing in the many technical journals and is not a complete review of the journal. The publications regularly reviewed appear below and the number given corresponds to the number following the title of the paper. The length of the article in pages, whether illustrated or not, is noted, and the publications reviewed in which it appears:

1. Canadian Engineer, Toronto, Ontario, Canada.
2. Cement, New York, N. Y.
3. Cement Era, Chicago, Ill.
4. Cement World, Chicago, Ill.
5. Concrete Age, Atlanta, Ga.
6. Concrete Era, Los Angeles, Cal.
7. Concrete-Cement Age, Detroit, Mich.
8. Concrete and Constructional Engineering, London, England.
9. Engineering and Contracting, Chicago, Ill.
10. Engineering News, New York, N. Y.
11. Engineering Record, New York, N. Y.
12. Good Roads Magazine, New York, N. Y.
13. Portland Cement, Kansas City, Mo.
14. Rock Products, Chicago, Ill.
15. Proceedings American Railway Engineering Association, Chicago, Ill.
16. Western Contractor, Record Building, Kansas City, Mo.
17. Journal National Fire Protection Association, Boston, Mass.
18. Journal Western Society of Engineers, Chicago, Ill.
19. Proceedings American Society of Civil Engineers, New York, N. Y.
20. Proceedings American Society of Municipal Improvements, New York.
21. Proceedings American Society for Testing Materials, Philadelphia, Pa.
22. Proceedings Engineers' Club of Philadelphia, Philadelphia, Pa.
23. Proceedings Engineers' Society of Western Pennsylvania, Pittsburgh, Pa.
24. Professional Memoirs, Corps of Engrs., U. S. A., Washington, D. C.
25. Proceedings Institution of Civil Engineers, London, England.
26. Transactions, Canadian Society of Civil Engineers, Montreal, Quebec, Canada.
27. Railway Age Gazette, Chicago, Ill.
28. Better Roads, Jamestown, Ohio.

MATERIALS

How to Insure Minimum Cost and Prompt Delivery of Steel Reinforcing Bars, by A. D. Mellor. (11) Oct. 3, 2 pp., ill. Discussion of items affecting cost and prompt shipment.

Specifications for Sand for Concrete, by Ernest McCullough. (3) Oct., 1 pp. ill. Granulometric analysis of sands.

DESIGN AND TESTS

True Pressure Line in the Masonry Arch, by Walter M. Smith. (11) Oct., 3 pp., ill. Graphical determination by the method of least work.

Fire Test of a Metal Lath Wall. (10) Oct. 1, 1/2 pp.; (4) Oct., 2 pp. ill. Abstract of report of test made at Columbia University Fire Testing Station. Temperature 1700° F. for 2 1/2 hours; wall subjected to water pressure of 30 lbs. suffered no injury.

Mechanics of Slabs Under Flexure, by C. A. P. Turner. (3) Oct., 3 pp.; (1) Oct. 8, 3 pp. Discussion of bond shear applied to flat slabs.

Permeability Tests on Gravel Concrete, by M. O. Withey. (3) Oct., 1 pp.; (10) Oct. 22, 1/3 pp.; (4) Oct., 2 pp. Results of tests made at University of Wisconsin.

Pile Testing as Practiced with Pedestal Piles. (10) Oct. 22, 1 pp. ill. Description of method of testing piles and reference to soil bearing test data.

An Instance of Lightning on a Steel Dome and Reinforced Concrete Walls. (10) Oct. 29, 1/2 pp. Lightning effectively handled by reinforcement thoroughly grounded.

Effect of Electrolysis on the Compressive Strength of Cement and Concrete. (1) Oct. 29, 2 pp., ill. Report of continued experiments by C. E. Magnussen, showing that for the current density covered by the experiments, there is no change in the compressive strength of the cubes.

BUILDINGS

Reinforced Concrete at the Ilkestone Secondary Schools. (8) Oct., 4 pp. ill. Description and cross-section of dome of 45 ft. span and 23 ft. rise.

The Theatre Des Champs Elysees, Paris. (8) Oct., 8 pp. ill. Design and construction.

Rapid Construction of Technology Buildings. (3) Oct., 2 pp. ill. Description and layout of plant for concrete buildings of Massachusetts Institute of Technology. Concreting plant made up of seven co-ordinate units.

An Efficient Concrete Plant Used on the Toledo High School, by H. C. McClure. (7) Oct., 2 pp. ill. Description of concreting plant.

New Ruling on Reinforced Concrete Flat Slab Construction, by Building Department of Chicago. (9) Oct. 7, 1/2 pp. Summary of ruling on flat slab construction based on extensive tests.

Stadium for University of Michigan. (11) Oct. 31, 1 pp. ill. General description and design of concrete stadium to seat 52,000 spectators.

Failure of the Reinforced Concrete Custom House at La Ceiba, Honduras. (10) Oct. 29, 1 pp. ill. Description and cause of failure.

Common Prejudices against Concrete. (4) Oct., 2 pp. Arguments for contractors against common prejudices to concrete construction, such as difficulty of installing machinery and making changes, hard and dusting floors, dampness, etc.

Terrazzo Floors, by Charles R. Marsh. (4) Oct., 1 pp. Resumé of current practice.

HOMES

Concrete Cottage Designs. (8) Oct., 11 pp. ill. Competitive designs for cottages costing £125.

Concrete Septic Tanks. (4) Oct., 2 pp. ill. Details of design and construction.

Modern Concrete Bungalow Chimney, by Albert Marple. (4) Oct., 2 pp. ill.

Monolithic Reinforced Concrete Residence, by Jack Desmond. (4) Oct., 4 pp. ill. Description of one story 50 x 63 ft. house in California.

BRIDGES AND RAILROAD WORK

Concrete Trestle and Coal Bin. (10) Oct. 15, 1/2 pp. ill. Inclined 4 per cent grade trestle approach at Guthrie, Ky., with bin of 100 tons capacity.

Protecting Steel Work Against Locomotive Blasts. (10) Oct. 15, 3 pp. ill. Description of several methods for protecting steel work with concrete and cast iron in line of locomotive stack travel.

Illinois Central Concrete Pipe Trestle Work. (11) Oct. 3, 1 pp. ill. Description and design of two miles of concrete pipe trestles between Fulton and Memphis, Tenn.

Self-Supporting Concrete Arch Reinforcement of Structural Shapes. (11) Oct. 17, 1 pp. ill. Design of reinforcement for four large bridges, ranging from 125 to 200 ft. in length.

The New York Rapid Transit Railway Extensions, by F. Lavis. (10) Oct. 1, 8, 15 and 29, 23 pp. ill. Review of this proposed work, covering history, design, organization, etc.

Concrete Steps and Retaining Wall. (10) Oct. 1, 1 pp. ill. Description of flight of steps 145 ft. long with rise of 25 ft. Two transverse expansion joints.

A Reinforced Concrete Pile with Special Provisions for Jetting. (10) Oct. 8, 2 pp. ill.; (14) Oct. 22, 1 p. ill. Design and method of jetted concrete pile of new design. Water jet not only projects downward at bottom of pile, but also upward through various side openings.

Patching Concrete Retaining-Walls by a Concrete Spraying Machine. (10) Oct. 8, 1 pp. ill. Description and operation of machine which handles aggregate up to ¾ in.

Bridge with Ornamental Panels, by G. D. Steele. (3) Oct., 2 pp. ill. Colored tile panels in the parapets of cantilever arch concrete bridge in Philadelphia.

Concrete Buildings for Jersey Central. (3) Oct., 1 pp. ill. Description of concrete coaling station and two roundhouses.
Standard Culvert Designs. (3) Oct., 3 pp. ill. Designs for circular culverts, prepared by Iowa Highway Commission.
Concrete Poles and the Possible Maximum Loads on Pole Lines. (7) Oct., 1 pp. General discussion.
Reinforced Concrete Docks in North America. (1) Oct. 1, 6 pp. ill. General description of concrete dock construction in North America.
Reinforced Concrete Dock Failures. (1) Oct. 8, 2 pp. Review of causes of failures.
General Construction and Costs of Reinforced Docks. (1) Oct. 15, 3 pp. Discussion of various types of construction and costs.
New Hocking Valley Coal Dock at East Toledo, Ohio. (27) Oct. 9, 3½ pp. ill. Concrete coal pier 170 ft. wide, 900 ft. long with capacity for 40 cars per hour.
Design and Construction of the Larz Anderson Bridge over the Charles River, Cambridge, Mass. (9) Oct. 7, 4 pp. ill. 440 ft. long, one 76 ft. and two 65 ft. spans; 80 ft. wide.

BRIDGES AND RAILROAD WORK

Chicago, Burlington and Quincy Concrete Pile Trestles. (11) Oct. 24, 2/3 pp., ill. Dimensions and other features of standard adopted for single track to eliminate timber and exposed steel.
A Unique Reinforced Concrete Bridge, by Alfred C. Reese. (11) Oct. 31, 1/3 pp. ill. Description of 310 ft. articulated concrete bridge.
Cantilever Bridge Built to Resemble Concrete Arch. (11) Oct. 31, 2/3 pp. ill. Description of 201 ft. cantilever concrete bridge.
Tunnel Lining with Compressed Air Plant. (11) Oct. 31, 1 pp. ill.; (10) Oct. 29, 1 pp. ill.; (9) Oct. 21, 1 pp. ill. Compressed air plant for lining 800 ft. tunnel on C. B. & Q. R. R.
Lining Large Coal Bunkers by the Cement Gun Process. (10) Oct. 22, 1 pp. ill. Method of attaching reinforcement and lining 33 coal bunkers with cement mortar.
Reinforced Concrete Bridges. (27) Oct. 23, 1 pp. Summary of practice of railroads, as reported by Committee of American Railway Bridge and Building Association.
Short Span Highway Bridges, by F. O. Dufour. (4) Oct., 5 pp. ill. General description and method of constructing beam and flat slab highway bridges.

RESERVOIRS, DAMS, CANALS, ETC.

Mill Creek Sewer System in St. Louis. (11) Oct. 3, 10 and 17, 9 pp. ill. Description of $3,000,000 pressure tunnel project, with history of St. Louis sewers, details of original construction with first costs and repair charges. Design of various sections; analyses of arch, etc.
Arthur's Pass Tunnel in New Zealand. (11) Oct. 17, 3 pp. ill. Description and method of constructing a tunnel five miles long of concrete, lining crown with concrete blocks.
Proposed Water Storage on the Upper St. Maurice River, Province of Quebec. (11) Oct. 10, 2 1/2 pp. ill. Main features of reservoirs and dams of 160,000,000,000 cu. ft. capacity.
Experimental Levees with Concrete Paving and Sheet-Pile Cutoffs, Mississippi River, by C. O. Sherrill. (10) Oct. 8, 4 pp. ill. Tests for seepage on levees lined with concrete.
Lining Walnut Hill Reservoir at Omaha. (11) Oct. 24, 1 pp. ill. Method of lining reservoir with 6-in. layer of concrete to eliminate leakage.
Nine Foot Pre-Cast Concrete Pipe for Lining Pressure Tunnel in Baltimore. (11) Oct. 31, 2 pp. ill. Method of casting and handling 7900 ft. of reinforced concrete pipe.
Building a Concrete Sea Wall with a Special Floating Mixer. (10) Oct. 22, 1/2 pp. ill. Description of mixing plant and cross section of bulkhead.
Large Hydro Development of the St. Maurice River. (1) Oct. 22, 3 pp. ill. General description of 180,000 H. P. development, with details of contractor's plant.

ROADS AND PAVEMENTS

Private Road Over Seven Miles of Marsh and Loose Sand. (11) Oct. 10, 2/3 pp. ill. Description of concrete road at Cedar Point, Ia., of 6-in. slab, 24 ft. wide.
Concreting 25 Miles of Highways. (3) Oct., 4 pp. ill. Description of work in Milwaukee County.
Concrete Roads in Cook County. (3) Oct., 3 pp. ill. Description of work in Cook County.
Country Roads in Southeastern Wisconsin. (11) Oct. 24, 2 pp. ill. Description of roads, method of construction and general scheme of roads projected.
Design and Construction of Concrete Pavement, Village of Glencoe, Ill. (9) Oct. 21, 1 1/2 pp. ill. Design and method of constructing concrete pavement.

SEWERS, PIPE, TILE, ETC.

Collapsible Core for Reinforced Concrete Pipe Construction. (11) Oct. 3, 1/3 pp. ill. Details of wooden form employed at Catskill Aqueduct.
Concrete Pipe for Subaqueous Tunels, by J. C. Lathrop. (11) Oct. 3, 1 pp. ill. Methods and costs of 29 pipe sections layed at Baltimore.
Lining Pipe with Cement. (10) Oct. 8, 1/2 pp. ill. Description of apparatus for forcing cement mortar into pipes, and then pulling a set of cores through the pipe, producing a 1/8-in. lining of cement mortar.
Reinforced Concrete Sewer Designs for Construction in St. Louis, by W. W. Horner. (7) Oct., 5 pp. ill. Typical designs and tabulation of concrete arch sewers and discussion of arch design.

CONCRETE PRODUCTS

Concrete Posts and Poles. (27) Oct. 23, 2 pp. ill. Advantage, cost and method of constructing posts as reported by Committee of American Railway Bridge and Building Association.

The Concrete Block "Comes Back," by G. D. Crain, Jr. (4) Oct., 2 pp. ill. Description of concrete block.

MISCELLANEOUS

Concrete Work, Ornamental and Otherwise, by St. Louis Park Department. (7) Oct., 4 pp. ill. General description and costs of concrete work in parks.

Some Data on the Use of Slings in Handling Loads. (9) Oct. 7, 1 pp. ill. Data on the variation of stress in slings due to method of slinging.

Concrete Lumber for Mine Shafts. (11) Oct. 31, 2 pp. ill. Design and construction of concrete lumber used on the Mesaba iron range.

Concrete Benches for Greenhouses. (4) Oct., 2 pp. ill. Description and construction of greenhouse benches.

PART II. Papers, Discussions and Reports

(Forming part of Vol. X of *Proceedings*)

TEST OF A FLAT SLAB REINFORCED CONCRETE FLOOR AT SHREDDED WHEAT FACTORY, NIAGARA FALLS, N. Y.

By W. A. Slater.*

The Building.

The building tested, Fig. 1, is a new factory building for the Shredded Wheat Company at Niagara Falls, N. Y. It was built by Braas Bros., contractors, Niagara Falls. N. Y.. according

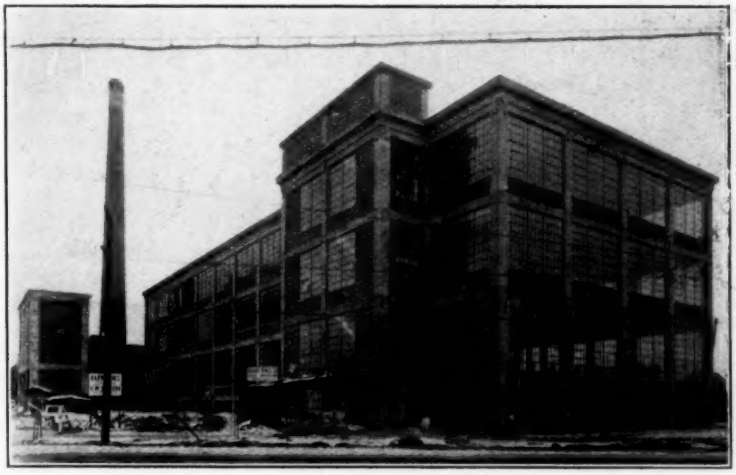


FIG. 1.—THE SHREDDED WHEAT FACTORY, NIAGARA FALLS, N. Y.

to plans prepared by the Corrugated Bar Company of Buffalo, N. Y., and conforming to their standard practice. Mr. Walter McColloh acted as consulting engineer for the Shredded Wheat Company and supervised the construction of the building. The main portion of the building is 265 ft. 4 in. long and 81 ft. wide.

* First Assistant, Engineering Experiment Station, University of Illinois, Urbana, Ill.

The floor is what is commonly known as a flat slab, and is divided into panels 20 ft. by 22 ft. The floor on which the test load was placed is the first above the basement. It was designed for 125 lb. per sq. ft. live load. The slab is 7 in. thick in the central portion of the panel and is increased to a thickness of 9 in. throughout the area of an 8 ft. 6 in. square surrounding each column. The columns are octagonal, 25 in. in the short diameter for the basement columns, and 22 in. in short diameter for the next story above. The interior columns terminate at the upper

FIG. 2.—UNDER SURFACE OF TEST FLOOR.

end in a pyramidal capital of octagonal form and 42 in. in short diameter. The pyramidal elements of this capital have a slope of 45 deg. with the horizontal. Fig. 2 shows the under surface of the test floor at the time of the test.

All the reinforcement is placed in two directions at right angles to each other. It is designed to resist positive moment at centers of all spans and negative moment at all points across the edges of the panels. Corrugated bars were used exclusively. Fig. 3 and 4 show the distribution of reinforcement in the test floor of this building.

An illustration of the method of interpreting the drawing is here given. The legend

$$\left.\begin{array}{l} 2 - \frac{1}{2}'' \text{ C.R. } 20' - 0''\text{s} \\ 2 - \text{“ Mk3} \end{array}\right\} 8'' \text{ Cts.}$$

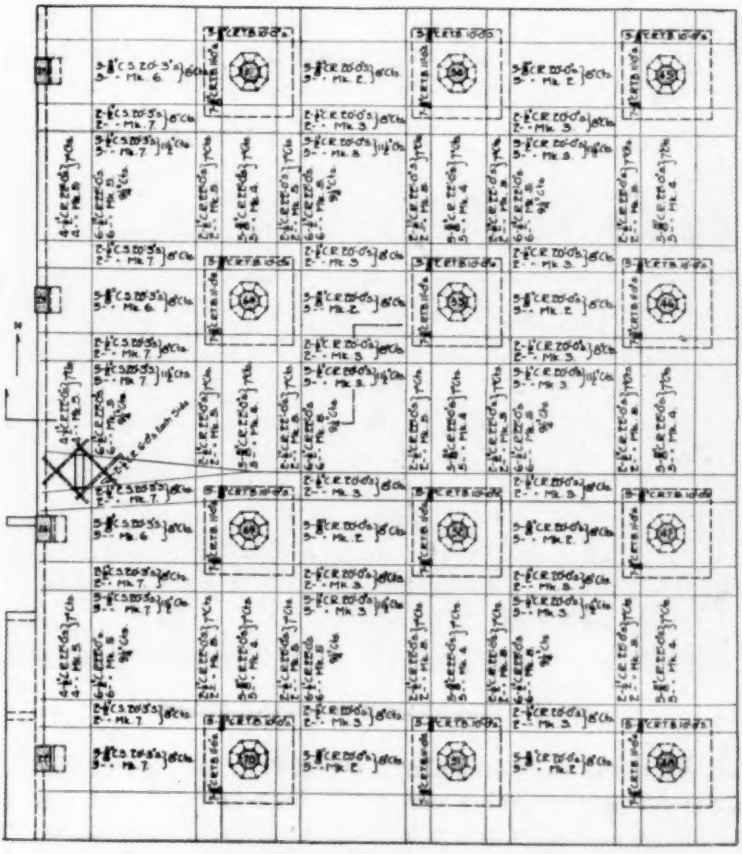


FIG. 3.—PLAN SHOWING DISTRIBUTION OF REINFORCEMENT.

is to be interpreted as follows:

2½-in. corrugated round bars, 20 ft. 0 in., straight.

2½-in. corrugated round bars. Mark 3. (See schedule of bent slab bars.)

All bars are placed in the direction of the lines of the notes describing them.

The above are bars staggered and placed 8 in. on centers.

Fig. 5 contains information as to the bending and supporting of bars and as to other details of the slab.

Gravel aggregate which made a good quality of concrete was used in this building. At the time of the test the concrete was about 80 days old. At the time of pouring the test floor four cylinders were cast. These were tested at the University of Illinois and showed an average strength of about 3500 lb. per sq. in., none falling below 3200 lb. per sq. in. The average initial

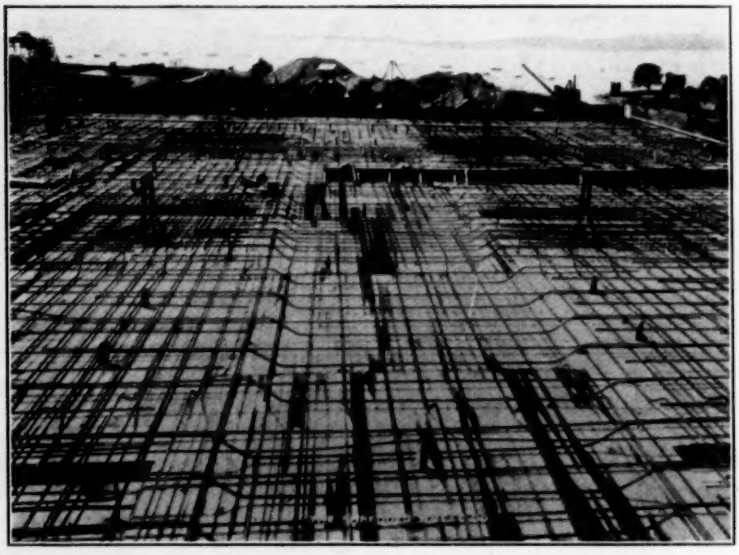


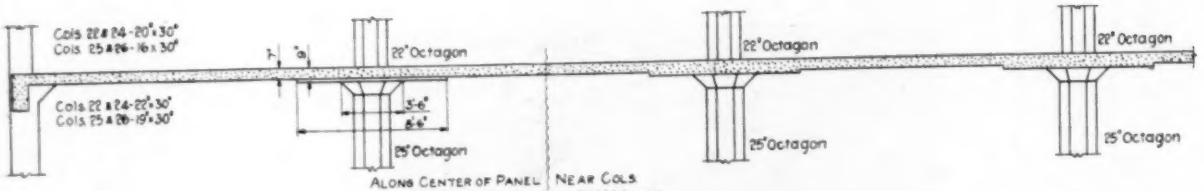
FIG. 4.—ARRANGEMENT OF REINFORCEMENT.

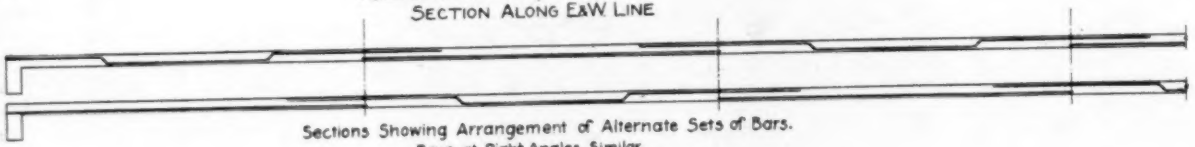
modulus of elasticity was about 5,000,000 lb. per sq. in., but for reasons stated in another paragraph this modulus is not used in calculating concrete stresses from the measured deformations.

METHOD OF TESTING.

Testing.—The general method of testing was the same as described by the writer in a paper* on "The Testing of Rein-

* See *Proceedings*, Vol. VIII, 1912, p. 168; *Proceedings*, Vol. VIII, 1912, p. 61, Report of Committee on Reinforced Concrete and Building Laws. See also *Bulletin* 64, University of Illinois Engineering Experiment Station, "Tests of Reinforced Concrete Buildings," by A. N. Talbot and W. A. Slater.

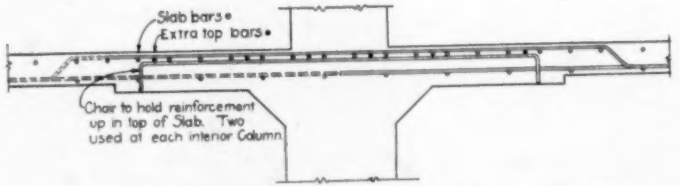




Sections Showing Arrangement of Alternate Sets of Bars.
Bars at Right Angles Similar.

SCHEDULE OF BENT SLAB BARS

MARK	SIZE	LENGTH	A	B	C	D	E	F
2	⅜ CR	29'-3"	9'-6"	5"	9'-0"	5"	9'-7"	5"
3	½ CR	29'-3"	9'-6"	5"	9'-0"	5"	9'-7"	5"
4	⅜ CR	32'-3"	10'-11"	5"	9'-3"	5"	10'-11"	5"
5	½ CR	32'-3"	10'-11"	5"	9'-3"	5"	10'-11"	5"
6	⅜ CS	25'-0"	9'-6"	5"	9'-0"	5"	9'-4"	5"
7	½ CS	25'-0"	9'-6"	5"	9'-0"	5"	9'-4"	5"



SECTION THRU TYPICAL INTERIOR COLUMN ALONG E&W LINE

FIG. 5.—BENDING OF BARS.

forced Concrete Buildings under Load." Strain gage readings were taken before applying any load. After a load had been applied readings were taken again and the change in gage length observed. Illustrations of the strain gages* used may be found in the paper above referred to.

The test was made on nine panels of the first floor of the building. The gravel used as loading material was raised by means of a concrete hoist to the second floor and there deposited

FIG. 6.—THE TEST LOAD IN POSITION.

into the hopper of a concrete chute. By moving the chute, the gravel was distributed as desired. Fig. 6 shows the load in position. The load covered the entire panel areas except for aisles 2 ft. wide extending from column to column and boxes about $3\frac{1}{2}$ ft. square placed in the center of each panel. These areas were left uncovered to afford convenient access to the gage lines. The cost of handling the material was borne by the

* See references, p. 388; also *Proceedings, Am. Soc. Test. Mats.*, Vol. XIII, p. 1027, paper on "The Use of the Strain Gage in the Testing of Materials," by W. A. Slater and H. F. Moore.

Corrugated Bar Company, who had an agreement with Braas Bros. for placing and removing gravel at a given price per cubic yard. The loads at which the strain gage observations were made have been taken as 56, 120, 191 and 243 lb. per sq. ft., respectively. Each increment of load was leveled carefully and the height recorded. At the maximum load, in order to ascertain the total weight per cubic foot of gravel as compacted, a box without any bottom was sunk through the gravel after the fashion of an open caisson. The gravel was shoveled out from the inside of the box and measured and weighed after it was removed, the box gradually being pushed nearer and nearer to the slab. This was continued until all of the gravel was removed from the interior of the box. The average depth of the gravel removed and the area displaced by the box were measured and thus the weight per cubic foot of gravel loose and as compacted on the floor were determined to be 113 and 134½ lb. per cubic foot, respectively. Only 79 per cent of the floor area was covered, hence the corresponding average weights per sq. ft. for the total test area were 84½ and 106½ lb. per sq. ft. of height of loose gravel and compacted gravel respectively. The exact condition of the gravel at all times as regards compactness is not known and the actual maximum load on the floor may have been as much as 250 lb. per sq. ft. instead of the 243 lb. assumed.

The 191-lb. test load covered nine panels as shown in Fig. 7. This load was allowed to remain in position 2½ days, after which the load was removed from the three wall panels and the three farthest from the wall. Finally, of the three panels still loaded the two outer panels were unloaded and the load on the central panel increased to 243 lb. per sq. ft. At each stage of the test the load was allowed to remain in position at least 12 hours before the final strain gage readings were taken.

For the purpose of taking readings of deflection, posts were set in proper position on the basement floor and extended upward to within about 8 in. from the bottom of the test floor. The observations taken were of the change of distance between a certain point on the top of each post and a corresponding point on the bottom of the test floor. The deflectometer used was designed by F. J. Trelease, Chief of the Research Department of the Corrugated Bar Company. In its general features it is

much the same as a deflectometer designed at the University of Illinois (see Fig. 20 on p. 202 of Vol. VIII of the *Proceedings*), but it has adaptations made by Mr. Trelease.

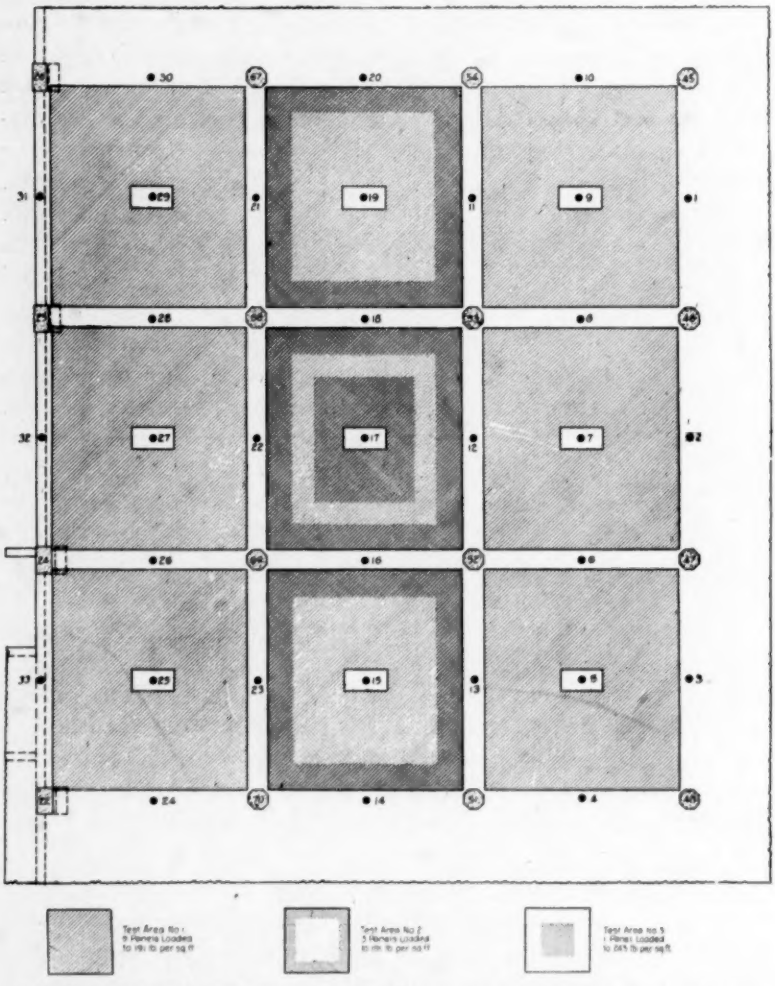


FIG. 7.—PLAN OF DISTRIBUTION OF LOAD AND LOCATION OF DEFLECTION POINTS.

The test was planned originally by Mr. Trelease. The writer, representing the Engineering Experiment Station of the University of Illinois, assisted in the final planning of and prep-

aration for the test. Mr. Trelease was in charge of the conduct of the test. He and the writer acted as observers; R. C. Overland and A. L. Boettler, of the Corrugated Bar Company, were recorders.

Scope of Test.—The deformation measurements were taken on 137 gage lines on reinforcement, and 151 gage lines on concrete (Fig. 8 and 9). Deflection readings were taken at 33 points (Fig. 7).

The arrangement of gage lines and the movements of loads were designed to give information on (1) effect of loading nine, three, and one panels, respectively, (2) distribution of stress across center and margin of panel, (3) moment of resistance of reinforcement stress at center and at supports of slab, (4) bending of columns.

In order to obtain information as to the effect on deformation of standing under load, readings were taken at the 191-lb. load immediately after completing the loading operation, and again after the load had been in place about 60 hours.

Acknowledgment.—The writer wishes to acknowledge his appreciation of the courtesy of the Corrugated Bar Company in making available for public use the complete results of the test, and in giving material assistance in the preparation of this report of the test.

RESULTS OF TESTS.

Load Stress Curves.—In order to gain some idea of the amount of confidence which may be placed in the results, the load stress curves have been grouped (Fig. 10 to 13), placing close to each other for purposes of comparison the curves for gage lines located in similar positions on the floor. These curves are for the 9-panel load (test area No. 1, Fig. 7) up to the first point at 191 lb. per sq. ft. The second point at 191 lb. per sq. ft. is for the 3-panel load (test area No. 2). The point corresponding to 243 lb. per sq. ft. is for the 1-panel load (test area No. 3). The curves are assigned numbers corresponding to those given in Figs. 8 and 9. The grouping of these curves is indicated by numbers corresponding to those given in the "Key to Grouping of Gage Lines," Fig. 14.

In plotting these load-stress curves the moduli of elasticity

used for steel and concrete were 30,000,000 and 3,000,000 lb. per sq. in., respectively. The initial modulus of elasticity determined from the control cylinders was about 5,000,000 lb. per sq. in. It was not used in calculating stress from deformations, because

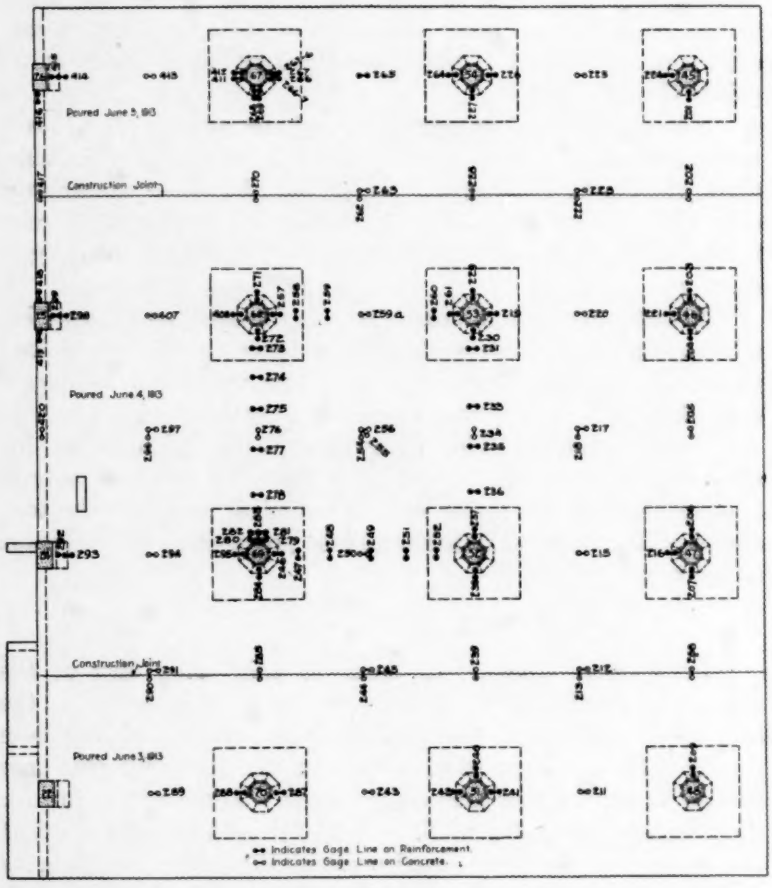


FIG. 8.—PLAN SHOWING LOCATION OF GAGE LINES ON UPPER SIDE OF FLOOR.

it seemed too high to represent the conditions in a large mass of concrete and because in any case the modulus at higher stresses is less than the initial modulus. It seems likely that the modulus for a small cylinder which dries rapidly would be greater than

that for a large mass of concrete. A value of 3,000,000 lb. per sq. in. seems amply large to represent the more extreme conditions of practice. Also this value is convenient for purposes of graphical representation since by using a scale of concrete stress

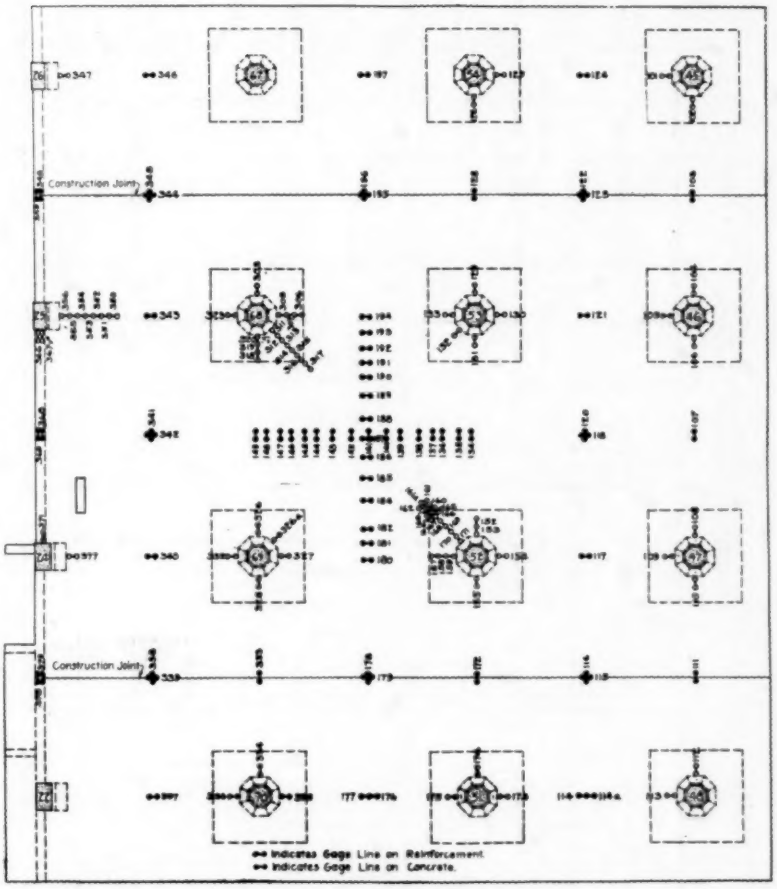


FIG. 9.—PLAN SHOWING LOCATION OF GAGE LINES ON UNDER SIDE OF FLOOR.

ten times as great as that of the reinforcement stress the deformations in concrete and reinforcement are shown to the same scale and may be compared directly.

These load-stress curves disclose some peculiar results which

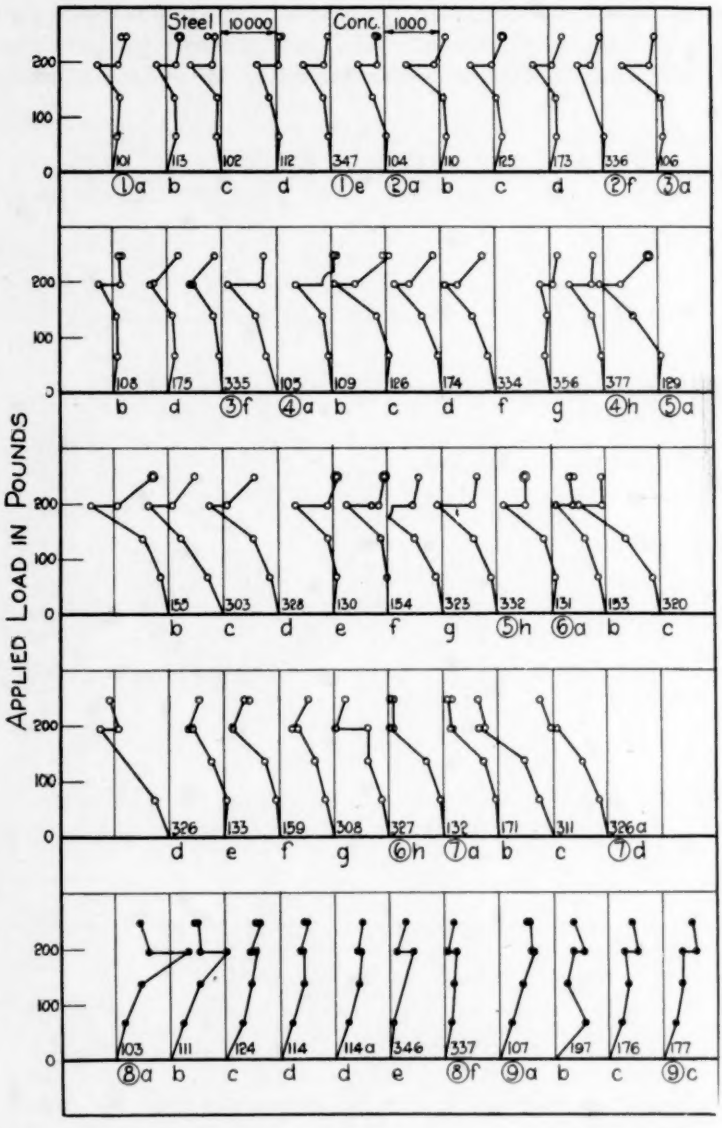


FIG. 10.—LOAD STRESS DIAGRAMS FOR UPPER SIDE OF FLOOR.

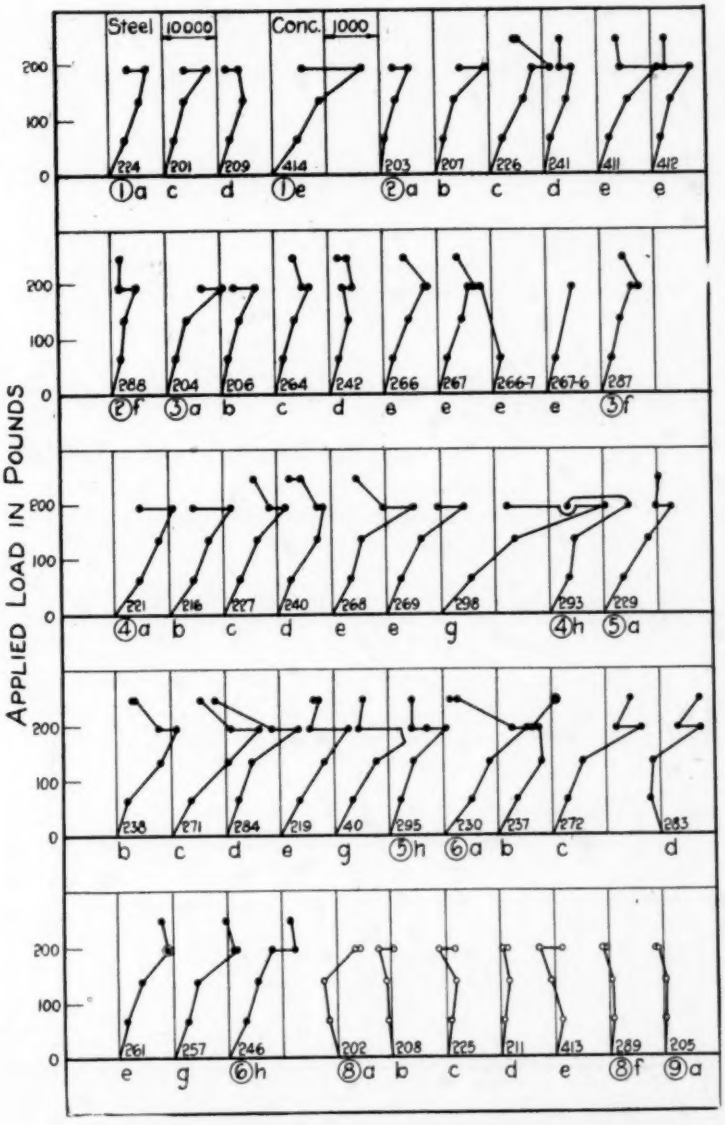


FIG. 11.—LOAD STRESS DIAGRAMS FOR UNDER SIDE OF FLOOR.

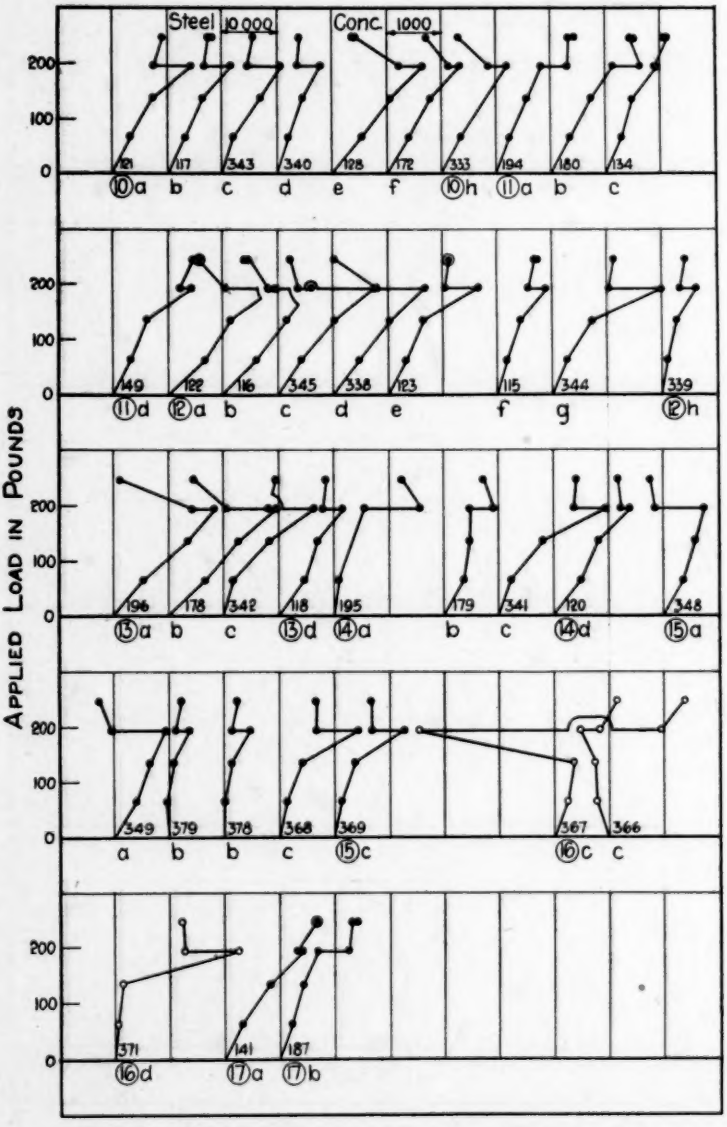


FIG. 12.—LOAD STRESS DIAGRAMS FOR UPPER SIDE OF FLOOR.

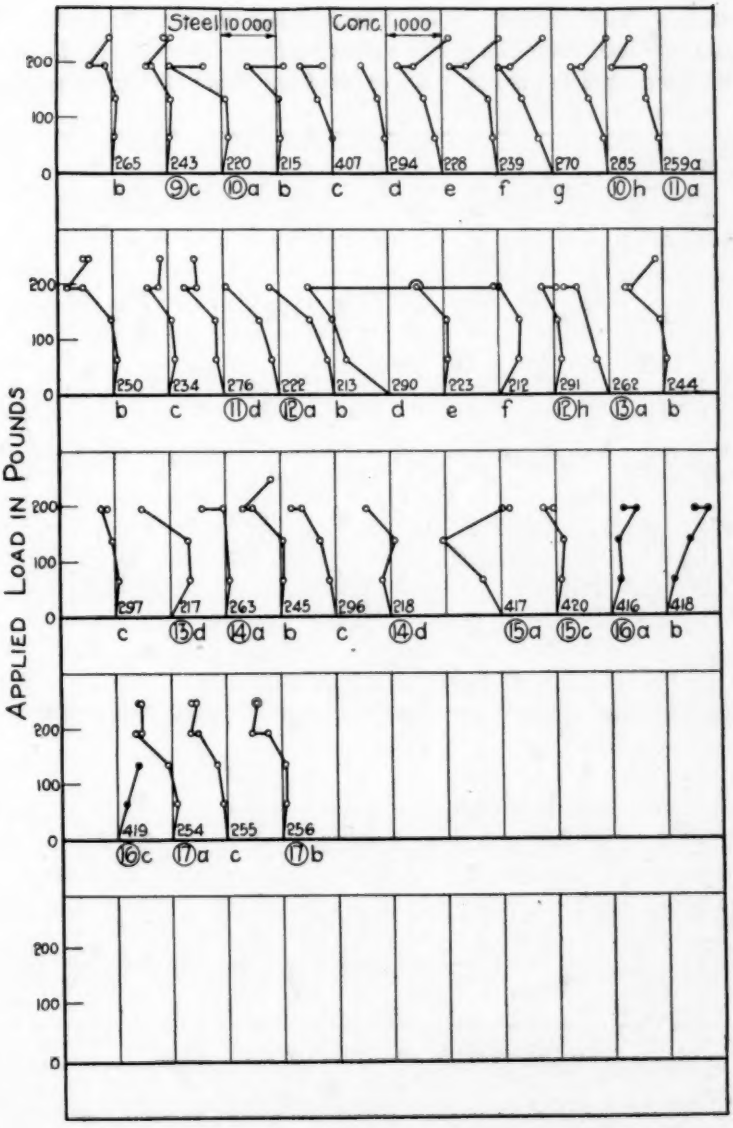


FIG. 13.—LOAD STRESS DIAGRAMS FOR UNDER SIDE OF FLOOR.

at first were discredited; however, the similarity of deformations found in positions remote from each other but similarly situated is so marked, even though the deformations be small, as to give confidence in the results. An example of this is found in groups

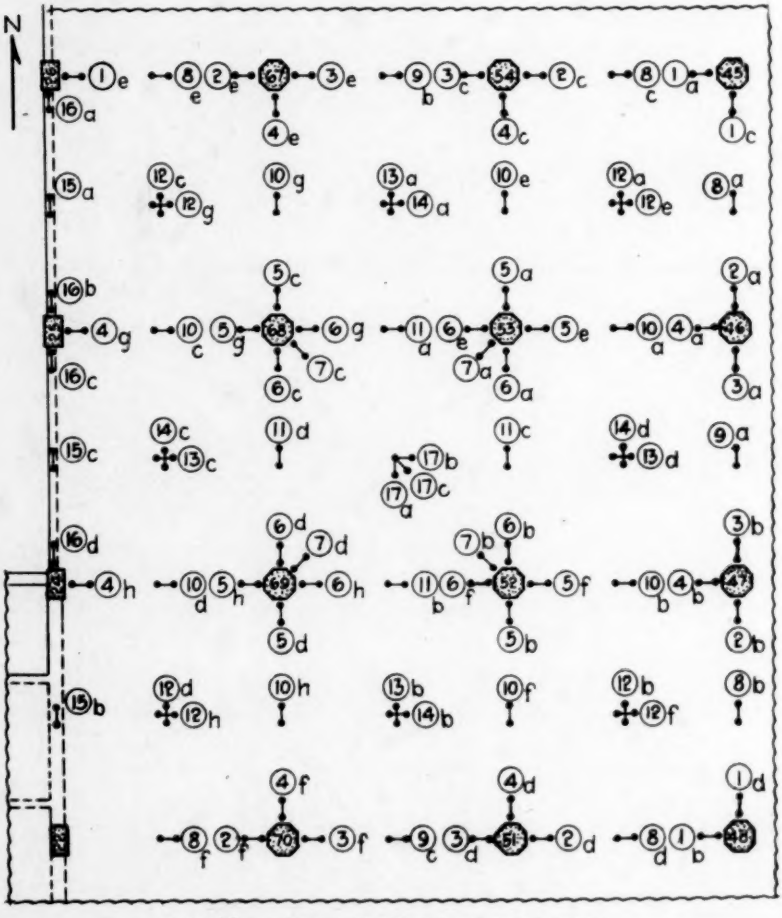


FIG. 14.—KEY TO GROUPING OF GAGE LINES.

1, 2 and 3, in which in several instances slight tension was found where compression would be expected. It is quite possible that these erratic results may be due to general changes in temperature of the concrete.

Examination of these curves showed that in all but a very small number of cases the removal of load from six panels caused the kind of change in the stress which would be expected from the nature of the change in loading.

Effect of Moving of Loads.—The removal of load from the six outer panels, that is, the change from test area No. 1 to test area No. 2, may be expected to have effects of different kinds. One of these effects will be to cause the three central panels in the north and south direction to assume a cylindrical deformation instead of the saucer-like deformation caused by the 9-panel load. This would result in the elements of the slab which extend in an east and west direction carrying the larger part of the load and consequently in their being more highly stressed than the north and south elements. This effect, when referred to later, will be termed the "cylindrical deformation effect." Another effect to be expected is that of lateral distribution of the stress in an east and west direction to the north and south elements. Previous studies of lateral distribution of stress in wide beams under concentrated loads make it clear that at, say, column 52 the stress in the north and south elements would be distributed well out into the unloaded panel toward column 47, thus reducing the stress in the element under the edge of the load. At the same column the stress in the east and west elements cannot be reduced by lateral distribution since in test No. 2 the three panels in the north and south direction are loaded. If the slab were perfectly fixed at the supports, so that a tangent to the slab at the column would be horizontal, the east and west elements would become more highly stressed both in the center and at the support than would the north and south elements. If the slab were freely supported the east and west elements would not have stress at the supports while the north and south elements would have stress at the two intermediate supports across which the loading is continuous.

Due to the change in load from test area No. 1 to test area No. 2 it may be expected that: (1) The "cylindrical deformation" effect will be to increase the stress in the east and west elements and to decrease the stress in the north and south elements. (2) The tendency of the lateral distribution of stress will be to reduce the stress in the north and south elements lying near the

edge of the loaded area and not to affect the stress in the east and west elements. (3) A bending moment will be developed in the columns.

Since all of these tendencies are operative simultaneously the problem of separating one from the others becomes very complicated.

Table I gives a summary of the results of an examination of the change of stress caused at the centers of the span by the change of load from test area No. 1 to test area No. 2. In all the cases from which this table was made up the stress in the east and west elements was appreciably increased. This increase may be due partly to the cylindrical deformation effect and partly to the bending of columns giving the effect of a simple beam instead of that of a continuous beam. If it is due to the former

TABLE I.—EFFECT OF CHANGE OF LOAD DISTRIBUTION ON REINFORCEMENT STRESS.

Position.	Cause of Change in Stress.	Total Change, per cent.
E. & W. reinforcement at center	Cylindrical deformation plus continuity	+66
E. & W. reinforcement at support	Cylindrical deformation minus continuity	−22
N. & S. reinforcement at center	Minus cylindrical deformation minus lateral distribution	− 9
N. & S. reinforcement at support	Minus cylindrical deformation minus lateral distribution	−31

entirely and not to the latter the stress at the support should be increased likewise, but instead Table I shows that, with few exceptions, the stress at the support decreases with the change of load. These exceptions all are in the case of bars which pass through a column or over a column capital. In all cases the bars which cross the panel edge at points intermediate between the column capitals lose part of their stress on changing the load from test area No. 1 to test area No. 2. These phenomena would indicate that if for purposes of comparison the slab were to be conceived of as a double system of strip-beams the strips passing through the columns could be considered as fixed at their supports while those passing between columns must be considered to have appreciably less end restraint. The increase of stress in the bars passing through the column may be due to the cylindrical deformation tendency, and except for this tendency it is possible

that the decrease in the stress in bars crossing the panel edge at points intermediate between columns would have been more marked. The average increase in reinforcement stress at the center of the span is 66 per cent and the average decrease in the reinforcement stress at the support is 21 per cent.

Table I shows also that the stress in the north and south elements of the slab was less for test area No. 2 than for test area No. 1. At the edges of the loaded panel the reduction in stress may be due partly to the cylindrical deformation effect and partly to lateral distribution of stress to the unloaded panel. Any effect of the former might be expected to be uniformly distributed across the loaded panel from column 69 to column 52, but any lateral distribution of stress must show up principally by reducing the stress at the edge of the loaded panel, that at the center (on gage line 249 for example) remaining unaffected by the change in load. The table shows that the gage lines in the center were affected fully as much as those at the edge, hence the principal agency in reducing the stress must be the cylindrical deformation tendency.

Table I indicates that in designing the reinforcement at the middle of a panel in a flat slab floor for the condition of all panels loaded the most severe conditions are not assumed. In the case of the building tested the stress at the center with only three adjacent panels loaded was 1.66 times that with nine panels loaded. It would have been of interest to make the same comparison of stresses with those for only one panel loaded, but since the load per square foot was greater when the single panel was loaded this comparison cannot be made directly. The comparison is made in another paragraph on the basis of coefficients of resisting moment developed by the reinforcement stress.

Resisting Moment of Reinforcement Stresses.—Table II contains calculated values of the ratio $\frac{M}{Wl}$ in which M = the summation of the resisting moments developed by the measured steel stresses, W = the total panel load in pounds and l = the average of the long and short panel lengths in inches. It is not assumed that this M represents the total resisting moment on the section considered because it must be recognized that in many cases the tensile strength of the concrete is of considerable assistance

in resisting the bending moment. For design, therefore, the coefficients given in Table II multiplied by Wl cannot be expected to give the total bending moment which must be resisted.

There are certain difficulties in the way of making accurately such calculations of resisting moment. For instance, the unknown effect on the value of jd of the sudden change of section at the edge of the depressed head may raise a question as to the correctness of the calculated resisting moment. This only emphasizes the fact above pointed out that the coefficients given in Table II are of value in a relative way only and do not give total moments. This table is of use in showing the relative bending moments at various positions and the increase in the proportional amount of bending moment resisted by the reinforce-

TABLE II.—CALCULATED MOMENT COEFFICIENTS.

Location.		Nine Panels Loaded. Load in lb. per sq. ft.			Average Coefficients.	One Panel Only Loaded, 243 lb. per sq. ft.
		56	120	191		
At Support	Long span	0.0207	0.0218	0.0315	0.0247	0.0216
	Short span	0.0151	0.0172	0.0174	0.0166	0.0138
	Sum	0.0358	0.0390	0.0489	0.0413	0.0354
At Center	Long span	0.0179	0.0160	0.0203	0.0181	0.0180
	Short span	0.0190	0.0163	0.0187	0.0180	0.0228
	Sum	0.0369	0.0323	0.0390	0.0361	0.0408

ment as the load increases. These coefficients all apply to the central panel of the loaded area. The total resisting moment of the reinforcement on a given section was obtained by taking the sum of the products of the measured reinforcement stress multiplied by the areas of the reinforcement and by the depths jd. Since the stress was not measured on all bars it was assumed that the stress varied uniformly from one gaged bar to the next. The value of jd was determined on the basis of the measured depth d and the calculated percentage of reinforcement.

Under the 9-panel load the tendency of the calculated moment coefficient in this table is to increase as the load increases. This increase should be expected as the concrete becomes less and less a factor in resisting the bending moment.

The table indicates that under the 9-panel load 50 per cent more moment was developed by the reinforcement stress at the support of the long span than at the support of the short span, while at the center more moment was developed in the short span than in the long span.

At the center of the short span the coefficient of the moment developed in the reinforcement with the single panel loaded to 243 lb. per sq. ft. (.0228 *Wl*) is 65 per cent greater than that of the moment developed with nine panels loaded to 191 lb. per sq. ft. (.018 *Wl*), this giving a close agreement with Table I which shows that with three panels loaded the stress in the center was 66 per cent greater than with nine panels loaded to the same intensity per sq. ft. At the support of the short span the coefficient of the moment of the reinforcement stress (.0166 *Wl*) is 17 per cent less for one panel loaded than for nine panels loaded, while Table I shows that at the same place the stress in the reinforcement was 22 per cent less with three panels loaded than with nine panels loaded.

Distribution of Stress and of Moments.—The Corrugated Bar Company uses as a basis of design of flat slabs the results of an admirable test* made by Mr. Trelease on a small rubber slab. The reinforcement in the flat slabs designed by this company is so distributed that the stress should be equal at all points along the support and at all points at the centers of the span if the rubber model test results are applicable. In order to see if these conditions are realized in practice, stresses developed in this test were plotted as ordinates and distance at right angles to the direction of the stress was plotted as abscissas in Fig. 15, 16, and 17. In some cases averages of stresses at similarly located gage lines have been shown. It cannot be said that in most cases a straight horizontal line fits the curve of observed stress satisfactorily, but neither would any curve which is symmetrical about a vertical axis fit it any better. The curves merely serve to show that the irregularities of construction may produce unaccountable variations in stress in adjacent bars. That these variations are not errors of observation is indicated by the fact that a set of check readings on a large number of gage lines gave stresses

* See *Proceedings*, Vol. VIII, 1912, p. 218, paper by F. J. Trelease on "The Design of Concrete Flat Slabs."

practically identical with those of the previous set of observations at the same load. An inspection of Fig. 22 indicates that the error of observation in the stresses as determined is very

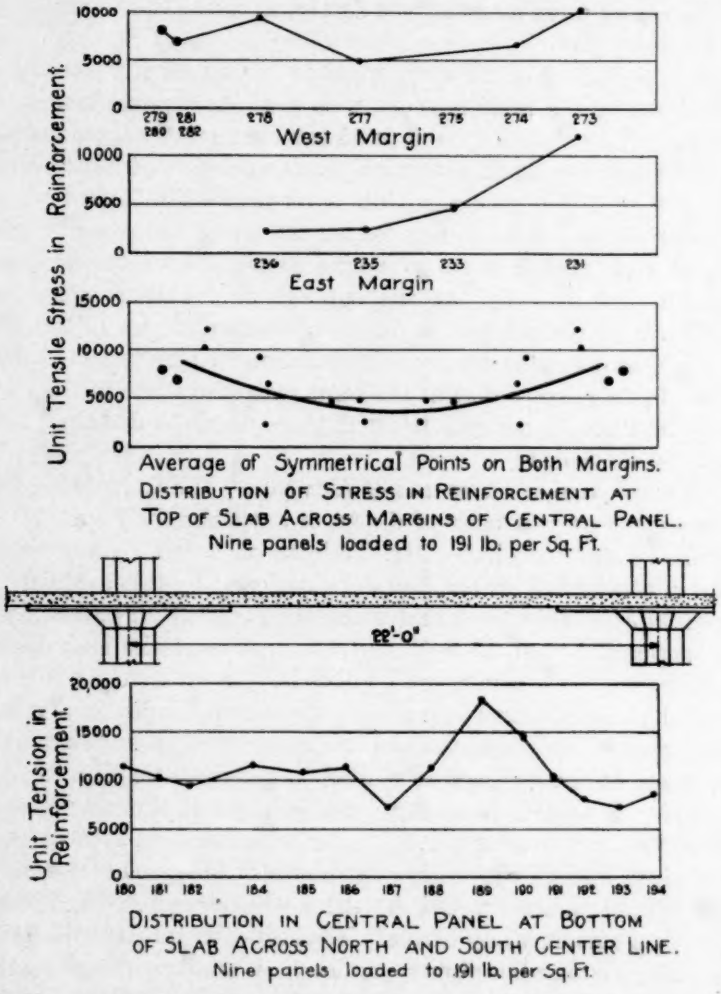


FIG. 15.—N. AND S. DISTRIBUTION OF STRESS IN E. AND W. BARS AT MARGINS OF PANEL.

small. Using the curve which seemed the most promising the resisting moments of the reinforcement were calculated at the points in the width of the slab at which measurements were taken.

These were reduced to moments in pound-inches per unit width and were plotted as B in Fig. 17. These values also were divided by Wl to obtain the moment factor. Finally these

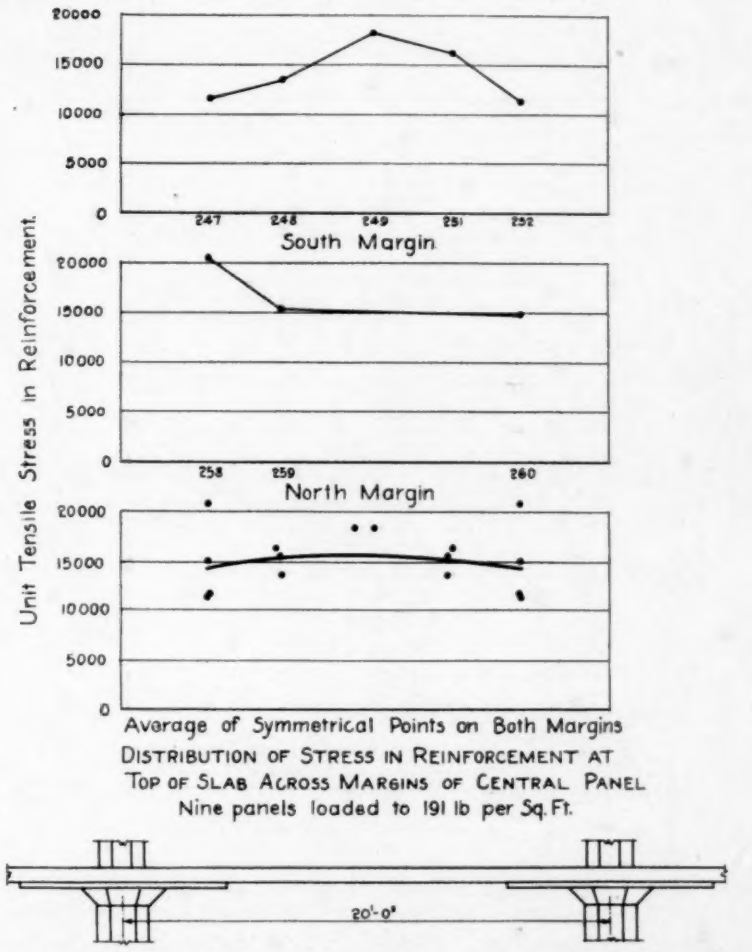


FIG. 16.—E. AND W. DISTRIBUTION OF STRESS IN N. AND S. BARS AT MARGINS OF PANEL.

moment factors were plotted as a heavy solid line (C) in the last curve of Fig. 17. The curved line is that obtained from the test of the rubber model previously referred to. The dashed

line shows the practical distribution of moment assumed in the design of floors. The total moment area under the heavy line is almost the same as that under the smooth curve. It should be

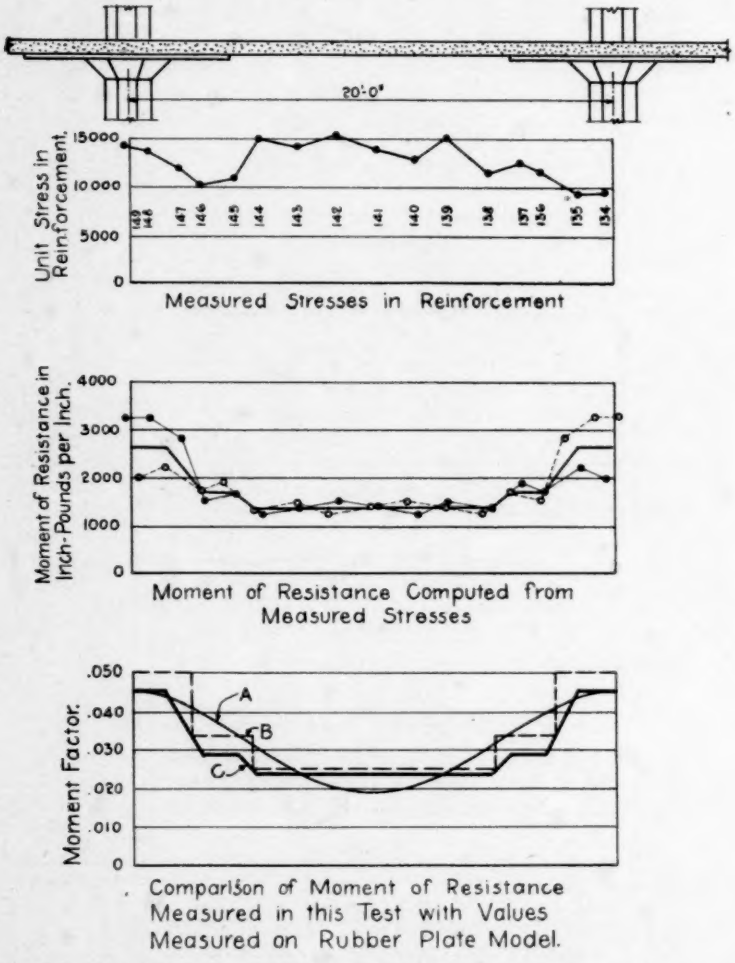


FIG. 17.—E. AND W. DISTRIBUTION OF STRESS AND MOMENT IN N. AND S. BARS AT CENTER OF SPAN.

expected if the concrete is assisting in carrying the load that the moment of the reinforcement stress should be considerably less than the total moment found in the rubber model test.

That is, the moment distribution curve for this test shows rather too close agreement with that for the rubber model test if the former represents only the moments of the reinforcement stress and the latter represents the entire moment.

Stresses in Columns.—Mr. G. A. Maney, research fellow, University of Illinois Engineering Experiment Station, has called the attention of the writer to a very useful relation between stresses in a column and those in the adjoining beam. The

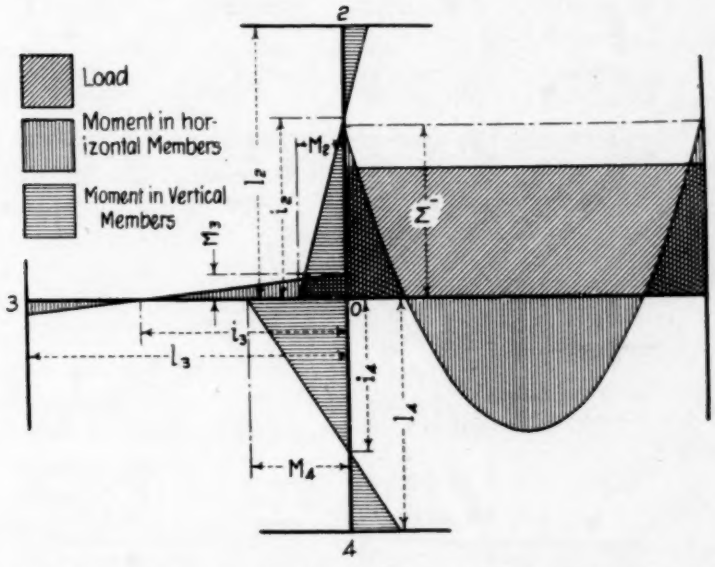


FIG. 18.—DISTRIBUTIONS OF MOMENTS IN BETWEEN TWO OR MORE RIGIDLY CONNECTED MEMBERS.

derivation which is here given is simple. Assume the beam to be supported on a column which extends through the beam. Assume the moments M_1, M_2, M_3, and M_4 in the respective members shown in Fig. 18. Assume that there is equal restraint at the ends of members 2, 3 and 4 and that there is no flexural load applied to members 2, 3 and 4 except that which is applied in their juncture. Dividing M_4 by M_3, Table III,

$$\frac{M_4}{M_3} = \frac{I_4\, l_3}{I_3\, l_4}$$

Now $f_4 = \frac{M_4 y_4}{I_4}$ and $f_3 = \frac{M_3 y_3}{I_3}$ in which f = flexural stress in any given fiber and y = distance from neutral axis to the fiber.

Therefore, $\frac{f_4}{f_3} = \frac{M_4}{M_3} \times \frac{I_3 y_4}{I_4 y_3}$. Substituting in this equation the value of $\frac{M_4}{M_3}$ as given above:

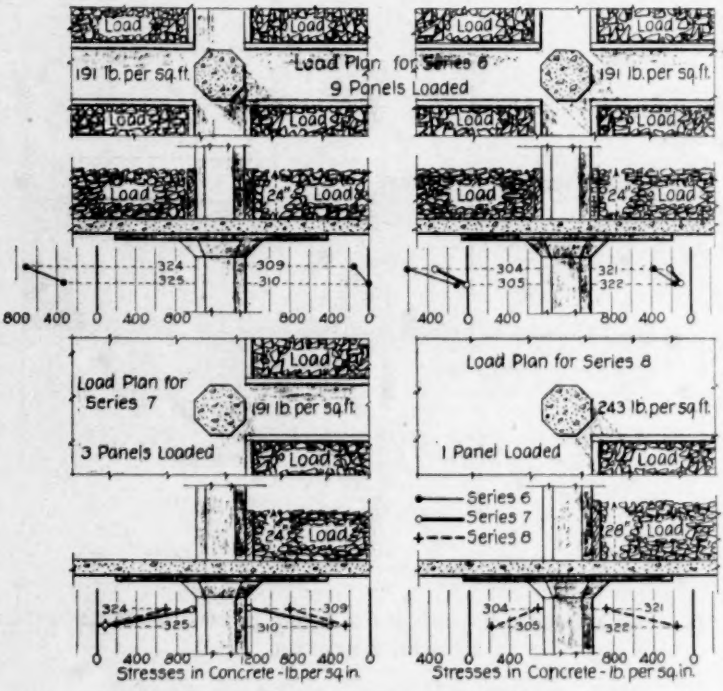


FIG. 19.—FLEXURAL AND DIRECT STRESSES IN COLUMNS.

$$\frac{f_4'}{f_3} = \frac{I_4 l_3}{I_3 l_4} \times \frac{I_3 y_4}{I_4 y_3} = \frac{I_3 y_4}{I_4 y_3}.$$

If a slab built into a column be assumed to bear the same flexural relations to the column as would a beam built into the column, this formula states that the ratio of stress in the column to the stress in the unloaded slab beyond the loaded panel is independent of all the properties of the column and slab except the spans and the distances from neutral axis to extreme fiber.

An application of the above formula is found in the test under consideration. Due to changing the load from test area No. 1 to test area No. 2 the following facts have been observed: The stress in the slab at the gage lines close to the column on the loaded area (see gage lines 308, 133, 327 and 159) in general increased somewhat or did not change. The stress in the slab at gage lines close to the column but just outside the loaded area (see gage lines 323, 332, 154, and 130) decreased very appreciably, and the stresses on both sides of the columns close to the connection with the floor increased very markedly, but, of course, in opposite directions on opposite sides (see gage lines 309 and 324, Fig. 19).

Formula (2) applies only to stresses set up by the moment M_1 and not to the direct compression in the columns due to load on the slab. Therefore, to apply this formula, the direct compression must be eliminated. Due to the removal of the load from the outer panels it seems probable that the compression due to direct stress will be reduced about one-half. Assuming then that the deformation under test area No. 2 is made up of one-half the direct deformation found in test area No. 1 plus the flexural deformation of the unbalanced load it is possible to determine the flexural deformation. Since there is no direct compression in the slab, no correction need be applied to the deformation found there in order to apply the formula. With the above assumption it is found that the flexural stress at gage lines 309 and 324 for test area No. 2 are 1168 and 1300 lb. per sq. in. (average 1234 lb. per sq. in.), and of opposite signs. The average stress at gage lines 323, 332, 154, and 130 is 296 lb. per sq. in. for test area No. 2. The ratio $\frac{1234}{296} = 4.17$. Substituting in the formula $\frac{f_4}{f_3} = \frac{I_3\, y_4}{I_4\, y_3}$ the proper values as nearly as they may be determined gives 5.7 as the calculated ratio $\frac{S_4}{S_3}$. The writer considers this a very satisfactory agreement between the formula and the results from the test. As much divergence as is here seen may find sufficient cause in uncertainties in determining the correct values to substitute in the formula, or in the fact that while the stresses referred to in the formula are those

at the point of intersection of beam and column those measured are of necessity at some distance from the intersection.

Moments in Columns.—The problem of the actual magnitude of the moments carried by the columns and by slabs involves so many uncertainties that a lengthy discussion of it seems unprofitable at the present, but a consideration of the values obtained on the basis of certain assumptions will give some idea of the way in which the moments may be expected to be distributed

TABLE III.—CALCULATED MOMENTS AT A RIGID JOINT.

Moment Considered.	Coefficient of Wl_1.		
	Algebraic Expression.	Numerical Equivalent.	
		Concrete not Intact.	Concrete Intact.
	Ends farthest from rigid joint fixed.		
M_1	$*C \frac{1}{6(1+2C)}$	0.0820	0.0755
M_2	$\frac{Il_1}{I_1l_2} \frac{1}{6(1+2C)}$	0.0228	0.0177
M_3	$\frac{Il_1}{I_1l_3} \frac{1}{6(1+2C)}$	0.0029	0.0154
M_4	$\frac{Il_1}{I_1l_4} \frac{1}{6(1+2C)}$	0.0563	0.0424
	Ends farthest from rigid joint free.		
M_1	$C \frac{1}{8(1+3/2C)}$	0.0834	0.0834
M_2	$\frac{Il_1}{I_1l_2} \frac{1}{8(1+3/2C)}$	0.9232	0.0196
M_3	$\frac{Il_1}{I_1l_3} \frac{1}{8(1+3/2C)}$	0.0295	0.0170
M_4	$\frac{Il_1}{I_1l_4} \frac{1}{8(1+3/2C)}$	0.0571	0.0467

$*C = \frac{Il_1}{I_1l_2} + \frac{Il_1}{I_1l_3} + \frac{Il_1}{I_1l_4}$

among the columns and the slab. Fig. 18 represents a portion of the slab loaded as in test area No. 2. Assuming that that portion of the slab which carries load to the column by beam action in the direction of the short span may be considered as a beam independently of flexure at right angles to the span the distribution of the moment to the various members is as given in Table III.

In making these calculations it was first assumed that

columns 2 and 4 and slab 3 are fixed at the ends farthest from the load and that the concrete in the upper surface of the slab near the column has cracked and therefore does not assist in carrying tensile stresses.

It is recognized that in many cases the assumption that the columns are fixed at the ends is not justified, hence values of the moment coefficients were calculated for the case in which the columns and unloaded beams are freely supported at the ends farthest from the load. These values also are found in Table III. A comparison of the moments for the case of free ends shows a difference so small as to warrant the conclusion that moments at a rigid joint of flexural members are only very slightly affected by the conditions as regards fixity of the ends farthest from the rigid joint.

To see how much the results were affected by the assumption that the concrete was intact the moments were calculated, assuming that the concrete above the neutral axis had no strength. These values also are given in Table III. They show that M_3 is greatly different for the two cases. In the floor tested the reinforcement was embedded nearly 3 in. deep in the slab and this fact makes the difference between the two cases larger than would be found if the reinforcement were closer to the surface.

The expressions for moment in Table III are based on the assumption that the load W is uniformly distributed along beam 1, also that the moment of inertia is a constant in each case for the full length of the member.

Placing $I_3=0$ in the expressions for moment given in Table III and using the proper values of I_1, etc., gives a solution of the moments at the wall column. About the same quality of results is obtained by applying the formulas to these columns as is obtained in the case of the interior columns. Fig. 20 shows the results of a series of measurements of deformation in a wall column.

In spite of the uncertainties in the formulas here given for moment in columns, it seems that they may be depended upon to give relative values with reasonable accuracy, although the absolute values of stress will be uncertain due to several causes, among which are (1) the unknown amount of the resistance of concrete to tensile stress in the slab, (2) uncertainty as to the

modulus of elasticity for concrete, (3) the unknown distribution of loads to the different belts of reinforcement, and (4) the divergence from true beam action, on which the derivation of the formula is based.

It is of note that the interior columns appear to carry a large part of the moment from the loaded slab and that a small difference between sizes of the columns below and above the loaded

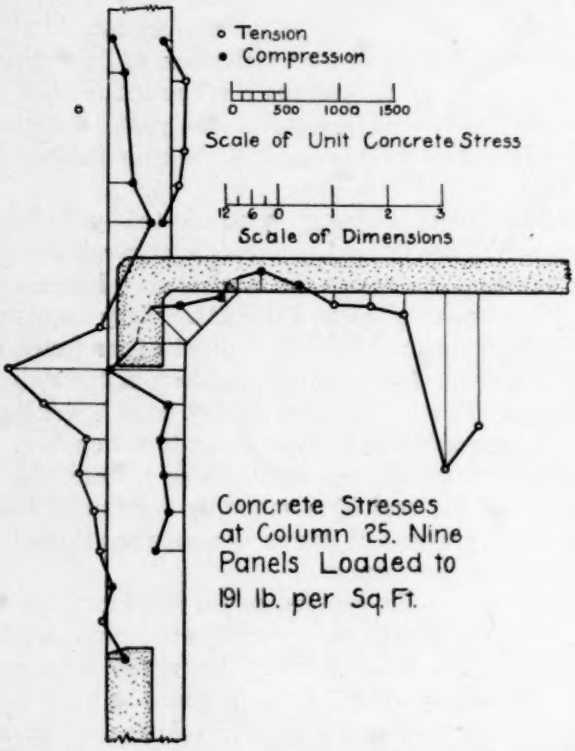

Tension
Compression
0 500 1000 1500
Scale of Unit Concrete Stress
12 6 0 1 2 3
Scale of Dimensions
Concrete Stresses at Column 25. Nine Panels Loaded to 191 lb. per Sq. Ft.

FIG. 20.—STRESSES IN A WALL COLUMN AND IN THE ADJACENT SLAB.

floor makes a large difference between the moments carried by the two columns; for example, the 9-in. slab carried only about 1/20 as much of the moment from the adjoining panel as does the 25-in. column supporting the slab and the 22-in. column above the floor carries less than half as much moment as does the 25-in. column below the floor. The difference between moments in

the two columns, however, is due partly to the difference in length of columns and not entirely to the difference in size. Undoubtedly the design of the higher floors of a building requires careful consideration on account of the decreasing size of the columns with the increasing height.

Point of Inflection.—Several series of measurements of deformations in concrete on the under side of the slab were taken in order to locate the point of inflection. The results of the measurements are shown in Fig. 21 and 22. Reference to Fig. 9 shows the location of these series of gage lines. In Fig. 21 only one series of measurements is carried far enough to show the actual position of the point of zero stress. The tendency of these curves to change their slope abruptly renders almost valueless any prediction as to where the curve produced would cut the zero line of stress. It is believed that the results are not directly comparable with those shown in tests of other floors since the measurements were taken entirely on the under surface of the slab. Some other tests have shown that the position of zero deformation of the under surface of the slab would be closer to the column than is the point of zero deformation of the upper surface. On the other hand, the Larkin Building test* reported by A. R. Lord indicated that the point of zero deformation of the upper surface was slightly closer to the column than that of the under surface. Until the reason for such variations in results found in different tests has been accounted for it seems unwise to base conclusions as to the position of the point of inflection on the data obtained from readings on the under surface only. These curves are of value, however, in showing that there is a tendency for the point of zero stress to move toward the column when the load is changed from test area No. 1 to test area No. 2. The tendency is exhibited in Fig. 21, though it is more marked in 21 (a) and 21 (b) than in 21 (c) and 21 (d). The movement of the point of inflection indicated in 21 (c) is consistent with the observation that the change of load from test area No. 1 to test area No. 2 caused a considerable increase of stress at the center of the panel.

Lintel Beams.—As the test progressed minute cracks were observed at positions of high stress and these confirmed the

* See *Proceedings*, Vol. VII, p. 156.

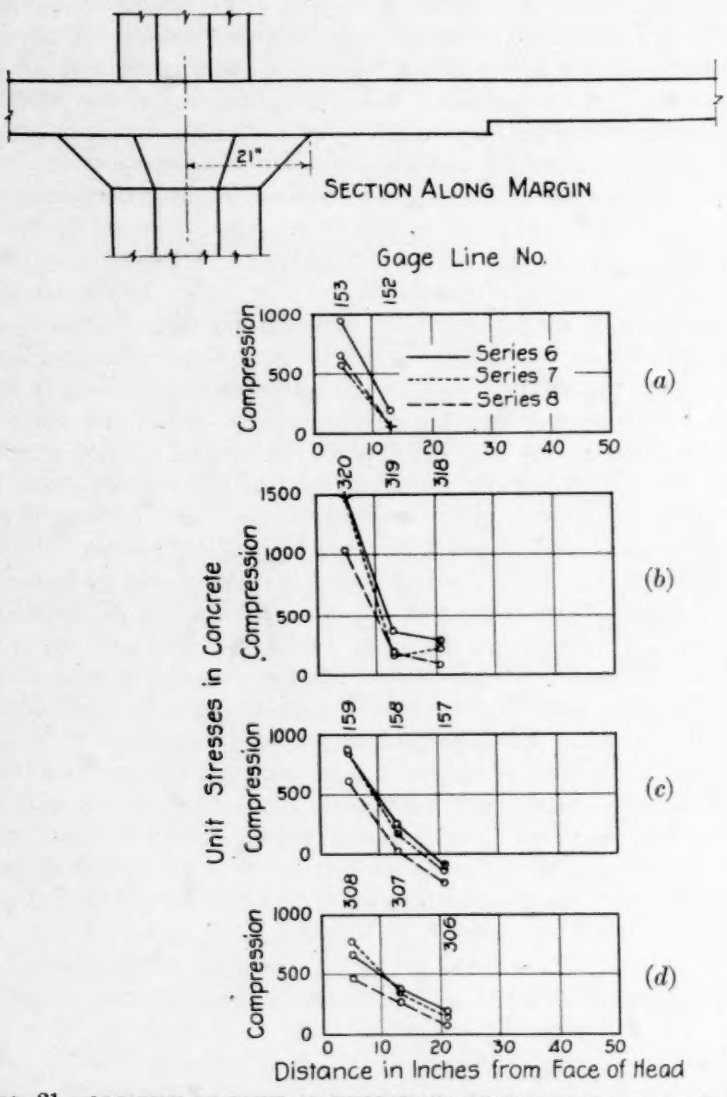


FIG. 21.—LOCATION OF POINT OF INFLECTION; RECTANGULAR DIRECTIONS.

Series 6; test area No. 1, 9 panels loaded to 191 lb. per sq. in.
Series 7; test area No. 2, 3 panels loaded to 191 lb. per sq. in.
Series 8; rest area No. 3, 1 panel loaded to 243 lb. per sq. in.
Abscissas = Deflection as per scale given.

results of the strain gage measurements. The most important indications of this kind were cracks which occurred in the lintel beams on the interior side near the ends. The cracks did not appear on the outside and except for this resembled the diagonal

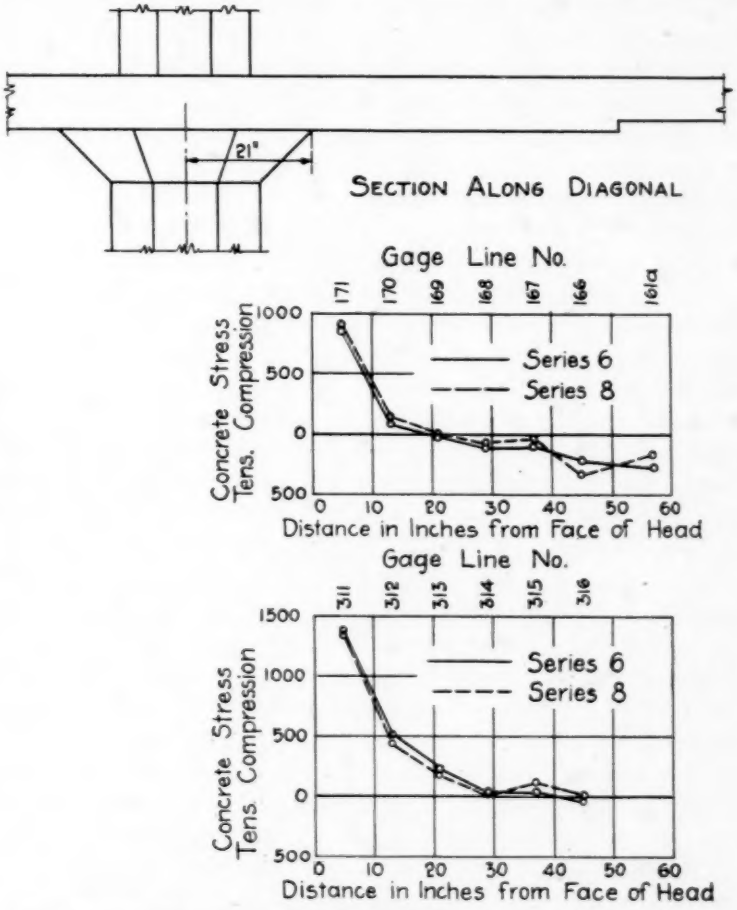


FIG. 22.—LOCATION OF POINT OF INFLECTION; DIAGONAL DIRECTION.

tension cracks ordinarily found in beams subjected to high shearing stress. The flexural stress in the beams indicated such a load on the beam as would develop a shearing stress of about 75 lb. per sq. in. The web reinforcement in this beam is of the

type commonly used by the Corrugated Bar Company. It consists of both inclined and vertical members wrapped about horizontal reinforcing bars. The presence of cracks on the interior and the absence of cracks on the exterior surface of the beam indicate that the torsion existing on this beam was a factor in causing cracks to appear. The shear due to torsion acts with the vertical shear on the interior and opposite to it on the exterior surface of the beam. This would tend to produce diagonal tension cracks on the exterior surface of the beam extending upward and toward the end of the beam, and on the interior surface extending upward and away from the end. Just such cracks have been found in the test of a large slab having a lintel without inclined web reinforcement.

In a lintel beam whose moment curve is symmetrical with respect to a horizontal axis normal to the span of the lintel the total torsion at a supporting column will be one-half of the bending moment produced in the slab at its juncture with the beam, provided that the columns supporting the ends of the lintel have equal moments of inertia about an axis parallel to the longitudinal axis of the lintel and provided that the torsional moment due to the eccentricity of any wall load on the lintel be neglected. If the lintel receives all its load from the adjoining panel by shear accompanied by a bending moment at the junction between the slab and the beam, the torsion at the end of the lintel is likely to be so large as to render impracticable the use of sufficient reinforcement to resist this torsion. This would emphasize the necessity of designing lintels for flat slabs so that the loads coming to them will be mainly superimposed loads. From this point of view it would seem desirable to have the slab freely supported by the lintel, so that any shear caused by the transfer of load from the slab to the lintel would not be accompanied by moment.

If it be necessary to build the lintel continuous with the adjoining slab so that the slab applies to the lintel not only a shear but a moment which must be resisted as torsion at the junction of lintel with column, then it is necessary to consider the torsion in the design of the lintel. The most effective section for resisting torsion is a circular section and the most practical approach to this in structural work is a square section. It is desirable then that as far as resistance to torsion is concerned

such a lintel should be as nearly square as is practicable. In addition an abundance of web reinforcement should be used. Since torsion increases the diagonal tension on the slab side of the lintel and decreases it on the opposite side the larger portion of the web reinforcement close to the junction of lintel and column should be placed on the slab side of the lintel.

Deflections.—Little use of measured deflections has been made in working up the report of this test, but since in many cities the required evidence of satisfactory design and workmanship is the meeting of certain specifications as to deflection under load it is believed that the presentation of deflection data may serve a useful purpose.

In Fig. 23 are given curves in which the ordinates represent load on the slab in lb. per sq. in. and the abscissas represent deflection in inches. Accompanying these curves are the numbers of the deflection points, the locations of which are shown in Fig. 7.

Summary.—At the expense of some repetition the following summary is given:

The building tested is the new factory of the Shredded Wheat Company at Niagara Falls, N. Y. It is of reinforced concrete construction of the flat slab type, three stories in height, and is divided by columns into panels 20 ft. by 22 ft. The test was made on the first floor above the basement story. This floor is 7 in. thick in the central portion of the panel, is 9 in. thick throughout the area of an 8 ft. 6 in. square surrounding each column, and is designed to carry 125 lb. per sq. ft. live load. The columns are octagonal in shape, those of the basement story being 25 in. in the short diameter and ending at the top in 3-ft. 6-in. flared heads. The columns of the story above are 22 in. in the short diameter. The reinforcement, all of which is placed in the two directions parallel to the sides of the panel, is designed to resist positive moment at the centers of all spans and negative moment at the columns and across the edges of all panels.

Originally nine panels were loaded to 191 lb. per sq. ft., after which the load was removed from six panels, leaving three adjacent central panels loaded. These three panels lie in a row and are one span removed from the exterior wall of the building.

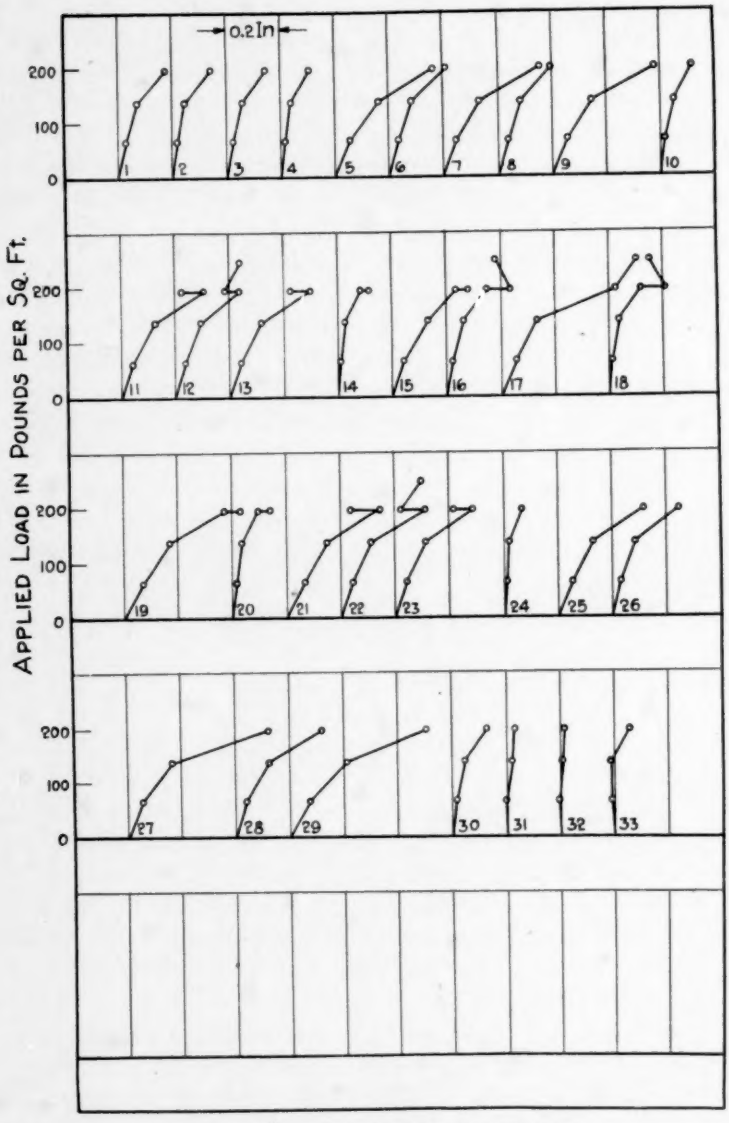


FIG. 23.—LOAD DEFLECTION CURVES.

Finally, the load was removed from all but one panel, the central panel of the entire test area and the load on this panel was increased to 243 lb. per sq. ft.

Deformations were measured at 288 gage lines and the results were very consistent among themselves. It was found that the condition of the three adjacent panels loaded gave reinforcement stresses at the center of the span more than 50 per cent greater than with nine panels loaded, and that the stress at the support was about 20 per cent less with three panels loaded than with nine panels loaded. It seems apparent that the tendency of the floor to deform as a cylinder instead of as a saucer, its action as a continuous beam, and lateral distribution of stress to unloaded portions of the slab all contributed to these differences between the stresses under 9-panel load and those under 3-panel load. The results of the test seem to check the conclusion arrived at analytically that the greater portion of the unbalanced moment was carried by columns and very little by the slab. This result when studied by itself appears to be in conflict with the observation that there was so great an increase in the stress at the center of the span when only three panels were loaded. When the fact is taken into consideration that it was mainly the strips intermediate between columns that showed this increase in stress in the center and a corresponding decrease of stress at the support due to changing the position of loads the conflict is partly removed.

The indications from this test are that the torsion in lintel beams due to unbalanced load is likely to introduce undesirable diagonal tension stresses.

This test has yielded results which are believed by the writer to be of scientific value. Some of the results from such tests which at first appear to be in conflict are shown by more complete analysis to be consistent with each other. Other results may appear consistent with each other when analyzed upon an incorrect basis and may lead to incorrect conclusions. Such conclusions are likely to be upset by other tests. Hence, while results of such tests as the one here reported usually are indicative of the general action of such a slab, deductions therefrom should not be expected to hold too rigidly as general and final conclusions.

REPORT OF COMMITTEE ON SPECIFICATIONS AND METHODS OF TESTS FOR CONCRETE MATERIALS

The work of the Committee during the past year has been chiefly the planning of tests of concrete to be carried on in various laboratories, and the compilation of the valuable results which are embodied in this report.

Tests of aggregates require, in the first place, investigations of methods of making up test pieces of concrete.

The object of these principal tests has been:

(1) To determine the size and shape of concrete test piece to recommend as a standard for tests of concrete in the laboratory and in the field, so as to obtain results as uniform and as comparable with actual conditions as practicable, and

(2) To determine the relative strength of concrete test pieces of different shape and size for comparison with the strength of test pieces of the standard shape.

In connection with these tests the series also included the effect of different consistencies in mixing upon the strength of concrete; the effect of varying the size of the coarse aggregate; the relative strengths at different ages and with different consistencies; and the effect upon the strength of different methods of storage of test pieces.

Besides these tests which are now being made, the Committee has planned tests to determine the relative strength of concrete test pieces made in the laboratory and test pieces of similar concrete cut out of the actual structure; and tests to determine the effect upon the strength of concrete of sand of different fineness. A part of this new work has been given out this winter to different laboratories.

The Committee also has under consideration:

The effect of different methods of storage upon the strength of test pieces.

Standard methods of capping compression test pieces preparatory to crushing.

Standard methods for making field test pieces.

Standard methods of determining weights of aggregate.

Standard sieves for analyzing sands and gravels.

Effect of chemical and mineralogical composition of the aggregate upon the strength of concrete.

CONCLUSIONS FROM TESTS OF CONCRETE.

As a result of tests made in the various laboratories, the following conclusions have been reached:

(1) The best shape of test piece is a cylinder. A height of double the diameter presents advantages over other proportions. Tests of similar cylinders show slightly less variation from each other than tests of square prisms or cubes. Where the height is double the diameter, the effect upon the strength of slight inequalities in height of different test pieces is eliminated. (See Fig. 1.)

(2) Cubes, cylinders or prisms, not shorter in height than their least diameter, can be used for comparative tests. For comparison with test pieces of standard shape, the strength of these may be corrected by a ratio. (See Fig. 1.)

(3) The smallest dimension of the test piece should be at least 4 times the size of the coarsest particles of stone. (See Fig. 4.)

(4) The shape of the test piece appreciably affects the strength.

(5) The strength of test pieces increases as the height decreases. Assuming a test piece whose height is double the width as a basis for comparison, a cube of the same mix will have about 37 per cent greater strength and a test piece whose height is half its width, about 109 per cent greater strength. As the length of the test piece becomes greater than 2 times the width, the strength decreases slightly. (See Fig. 1.)

(6) Tests of similar concrete made with different percentages of water tend to confirm conclusions previously established, that an increase in quantity of water in mixing reduces the strength of the concrete to a marked degree, and that this reduction is especially marked at the earlier ages. (See Figs. 5, 6 and 7.)

(7) The growth in strength with age, using different consistencies of concrete can be estimated. (See Fig. 5.)

The higher loads carried by test pieces which are shorter than one and one-half diameters are ordinarily attributed chiefly

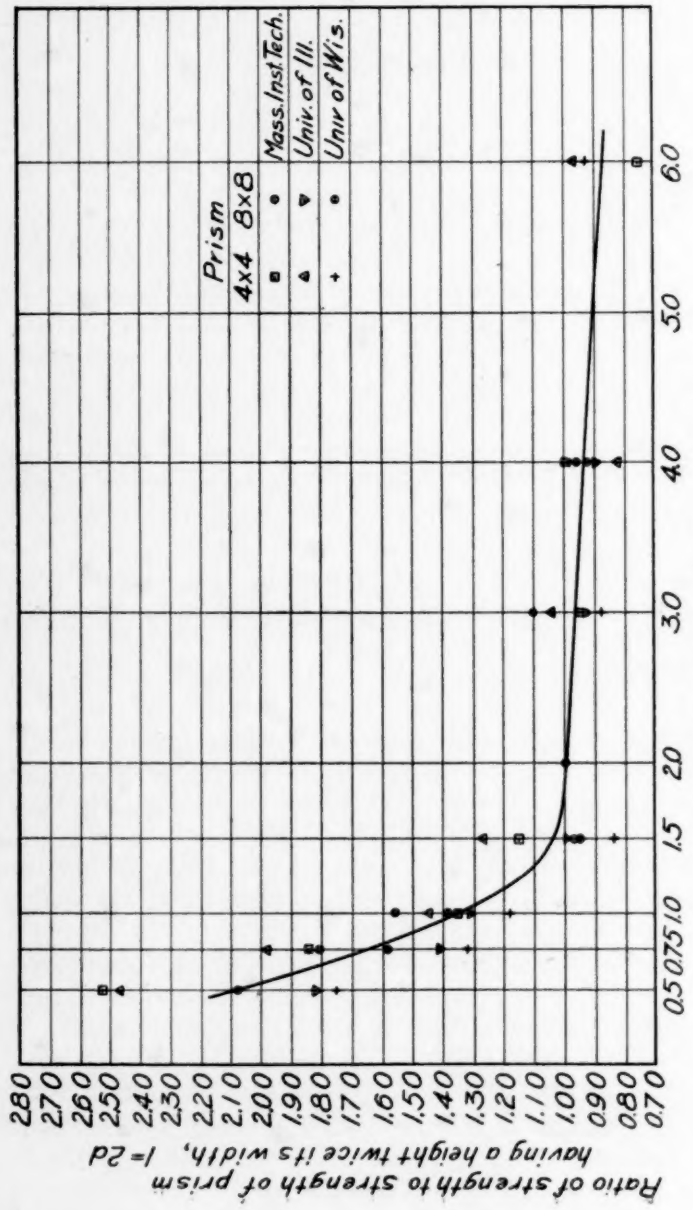

Ratio of strength to strength of prism having a height twice its width, l=2d
Ratio of height to width of prisms
Prism 4x4 8x8
Mass. Inst. Tech.
Univ. of Ill.
Univ. of Wis.
0.70 0.80 0.90 1.00 1.10 1.20 1.30 1.40 1.50 1.60 1.70 1.80 1.90 2.00 2.10 2.20 2.30 2.40 2.50 2.60 2.70 2.80
0.5 0.75 1.0 1.5 2.0 3.0 4.0 5.0 6.0

FIG. 1. COMPARATIVE STRENGTH OF CONCRETE PRISMS OF DIFFERENT HEIGHTS. (SEE TABLE 1.)

to the effect of the restraint against lateral swelling of the test pieces under load, which is developed by the friction between the bearing plates of the testing machine and the ends of the test piece.

Researches in literature and tests by individual members of the Committee indicate that the strength of concrete of given proportions increases as the size of the coarse aggregate increases. In the present series the results on this point are inconclusive, although tending in this direction.

The size of the test piece appears to affect the strength to

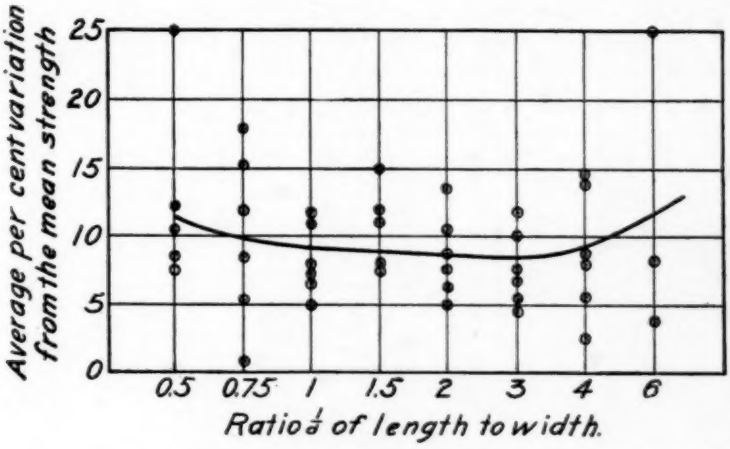


FIG. 2.—AVERAGE VARIATION IN STRENGTH FROM THE MEAN OF EACH RATIO L/D OF LENGTH TO WIDTH. (SEE TABLE I.)

a certain degree, but because of varying results in different laboratories, no definite conclusion has been drawn.

The method of storing the test pieces has a marked influence upon the strength of the concrete, Further tests on this point are necessary before drawing definite conclusions as to relative strength under different conditions. (See Tables V and VI.)

RECOMMENDATIONS.

1. It is recommended tentatively that the shape of the standard concrete test piece be a cylinder having a length of twice the diameter. The diameter should not be less than 6 in. except with very fine stone, when 4 in. may be adopted. It

appears advisable that the diameters of the cylinder should be at least 4 times the maximum size of the coarsest particles of the aggregate. The 8 by 16 in. cylinder, which has been adopted by the Joint Committee on Concrete and Reinforced Concrete is a satisfactory size when shipment of materials or other limiting condition does not preclude its use.

2. The strength of cubes or cylinders having a length equivalent to the diameter can be approximately converted to strength of cylinders of double the diameter by multiplying by 0.73.

TABLE I.—RELATIVE STRENGTH OF CONCRETE PRISMS OF DIFFERENT HEIGHT.† (See Figs. 1 and 2.)

Each Value is an Average of 4 Test Pieces. Normal Consistency. Proportion about 1 : 2 : 4. Age 3 months.

Ratio of Height to Width.	Average Ratios of Strength.*	Prisms 4 in. Square.				Prisms 8 in. Square.			
		Height of Prism, in.	Average Compressive Strength, lb. per sq. in.			Height of Prism, in.	Average Compressive Strength, lb. per sq. in.		
			Univ. of Ill.	Univ. of Wis.	Mass. Inst. Tech.		Univ. of Ill.	Univ. of Wis.	Mass. Inst. Tech.
0.5	2.09	2	6485	4320	5046	4	5408	4730	....
0.75	1.66	3	5170	3245	3672	6	4192	3596	4242
1.0	1.38	4	3811	2915	2688	8	3898	3143	3666
1.5	1.04	6	3306	2075	2288	12	2948	2260	2301
2.0	1.00	8	2623	2265	1993	16	2981	2263	2342
3.0	0.97	12	2732	2175	1910	24	2818	2146	2590
4.0	0.94	16	2137	2423	1976	32	2689	2145	2196
6.0	0.88	24	2513	2305	1883	..	....	....	....

* Ratio based on strength of prisms having height twice the width, $l = 2d$.

† Tests by University of California received too late to incorporate show much lower strength, probably because of finer sand, but the ratios of strength nevertheless agree substantially with the table values.

3. For field tests of concrete in actual construction, concrete should be taken from the loose mass after it is dumped from the barrow or other receptacle and before it is tamped or otherwise compacted.

4. The size of field test pieces should conform to the recommendations given above.

5. Field test pieces should be imbedded completely in sand located near the site of the structure and the sand kept continually moist until ready to ship to the laboratory. The test pieces for shipment should also be packed so as to retain their moisture.

SERIES OF TESTS.

The following series of tests have been made and reported by the various laboratories:

Series 1. Comparative tests of concrete to determine the variation in strength due to the size of the test piece, using aggregates of different maximum size.

Series 2. Comparative tests to determine the variation in strength due to the height of test pieces 4 in. square.

Series 3. Comparative tests to determine the variation in strength due to the height of test pieces 8 in. square.

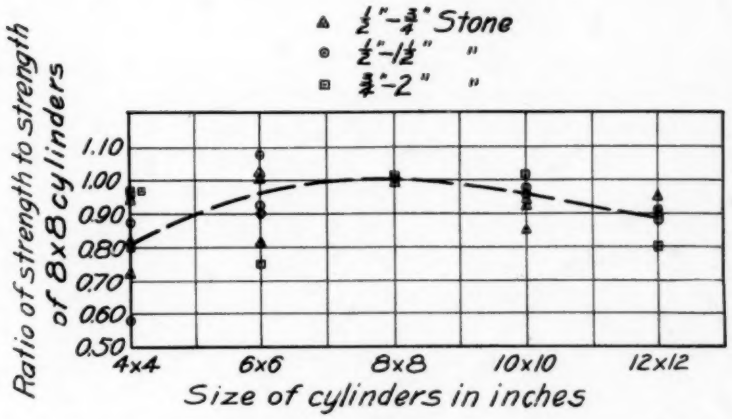


FIG. 3.—RATIO OF STRENGTH OF CYLINDERS OF DIFFERENT SIZES BASED ON 8 X 8 IN. CYLINDERS AT 1.00. RESULTS NOT CONCLUSIVE. (SEE TABLE II.)

Series 4. Comparative tests of strength of cylinders versus cubes and prisms.

Series 5. Growth in strength of concrete using different consistencies.

TESTS BY VARIOUS LABORATORIES.

The Committee desires to express its appreciation of the co-operation of the various laboratories, without which the successful issue of the tests would have been impossible. The actual strengths of similar test pieces in the different laboratories vary, as is to be expected, because of differences in character of aggregates and other local conditions. Since, however, the

object has been to attain comparative results rather than actual strengths of concrete, the variation between the different laboratories does not affect the value of the results, but rather adds to the general applicability of the conclusions.

Laboratories selected by the Com nittee for the tests and which co-operated are:

University of California, Prof. Charles Derleth, Jr., and Mr. Arthur C. Alvarez.

University of Illinois, Prof. Arthur N. Talbot and Mr. D. A. Abrams.

Massachusetts Institute of Technology, Prof. H. W. Hayward.

TABLE II.—RELATIVE STRENGTH OF CONCRETE CYLINDERS OF DIFFERENT SIZES. (See Figs. 2 and 3.)

Coarse Aggregate ½ to ¾ in. Each Value is an Average of 4 Test Pieces. Normal Consistency. Proportions about 1 : 2 : 4. Age 3 months.

Cylinder.		Average Breaking Strength, lb. per sq. in.			
Diameter, in.	Height, in.	Univ. of Ill.	Univ. of Wis.	Mass. Inst. Tech.	Average.
4	4	3154	2570	2662	2795
6	6	3386	3200	3042	3209
8	8	3350	3140	3705	3398
10	10	3141	2890	3117	3049
12	12	3012	2965	....	2988

Purdue University, Prof. W. K. Hatt.

Valparaiso University, Mr. Roland E. Anthony.

University of Wisconsin, Prof. M. O. Withey.

Of these the University of Illinois, Massachusetts Institute of Technology, and University of Wisconsin, carried out practically the complete series, and many of the tables and diagrams are based on the results from these three laboratories. The test pieces were made up under the direction of practical men accustomed to handling commercial work and ith large experience in laboratory work, so that the results may be accepted as representative of the best workmanship.

LAYOUT OF TESTS.

The instructions for tests issued by the Committee go fully into the exact methods of manufacture. To eliminate as far as

possible inequalities in proportioning individual test pieces, the test pieces were made up individually, using separate lots of material, weighed out separately, for each test piece.

NORMAL CONSISTENCY.

In one series of tests are included test pieces of different consistency. In most of the series what is termed "normal consistency" is adopted throughout. Because of the difference in the effect of different sands upon the consistency, it was impossible to specify a definite percentage of water. Tests made by

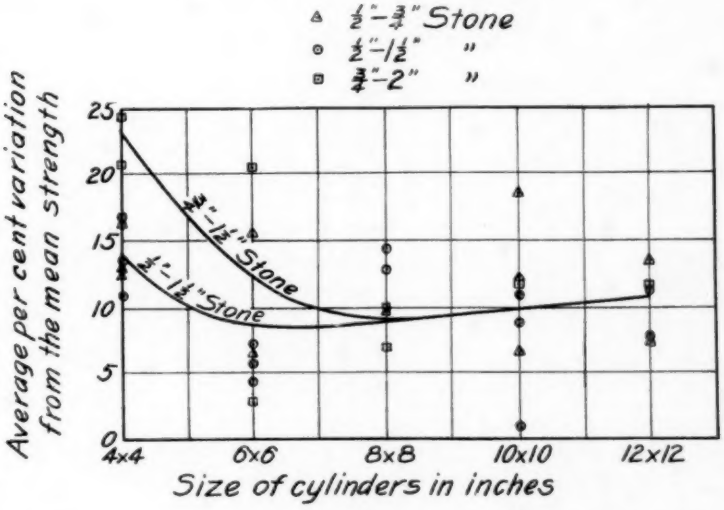


FIG. 4.—AVERAGE PER CENT VARIATION IN STRENGTH FROM THE MEAN OF EACH SIZE OF CYLINDER. (SEE TABLE II.)

members of the Com nittee indicate that the most uniform degree of consistency can be obtained by adopting the Chapman consistency test, which consists in filling a slightly tapering cylindrical form with concrete, immediately withdrawing this mold and by repeated trials finding the amount of water which will cause the concrete to just begin to slump when the form is removed. A dry mix is of course unsatisfactory, while it is almost impossible to describe a very wet mix which will insure uniformity.

It is appreciated by the Committee that the normal consistency selected is not nearly so wet as is ordinarily used in

reinforced concrete construction. In actual construction, however, the concrete is machine-mixed, which tends to give a higher strength than hand-mixed concrete, but the difference would not be marked when the concrete is mixed by hand in very small quantities, as was the case in making these test pieces. Furthermore, incidental tests of pieces of concrete cut out from the interior of the concrete in actual structures, while not as yet by any means conclusive, tend to indicate a higher strength than can be obtained normally from individually molded test pieces.

In view of these considerations, a plastic consistency, such as is described above, may be tentatively adopted as a "normal consistency" for use in making test pieces.

TABLE III.—COMPARATIVE STRENGTH OF CONCRETE CUBES AND SQUARE PRISMS VS. CYLINDERS OF DIFFERENT SIZES.

Each Value is an Average of 4 Test Pieces. Nornmal Consistency. Proportions about 1 : 2 : 4. Age 3 months.

Size, in.	Average Compressive Strength, lb. per sq. in.							
	Univ. of Ill.		Univ. of Wis.		Mass. Inst. Tech.		Average.	
	Prisms.	Cylinders.	Prisms.	Cylinders.	Prisms.	Cylinders.	Prisms.	Cylinders.
6 x 6	3711	3290	3010	2690	3575	3222	3432	3064
8 x 8	3521	3374	3135	2965	3917	3165	3524	3168
6 x 12	2547	2351	2245	2825	2440	2297	2411	2491
8 x 16	2759	2769	2260	2370	2496	2934	2505	2691

AVERAGE VARIATION FROM THE MEAN.

One of the principal objects of the tests has been the determination of the shapes and sizes of test pieces which would give the least amount of variation between individual pieces supposed to be identical. For this purpose what is termed in physical measurement the "average variation from the mean" was figured for each set of similar test pieces. The percentages given in Figs. 2, 4 and 8 show the average variation in strength which may be expected from the average strength of test pieces in a group.

WEIGHT OF CONCRETE VERSUS STRENGTH.

Examination of the various tests shows that exceptionally low strength is coincident with exceptionally low weight per

cubic foot of the concrete. Previous tests made by members of the Committee indicate that, eliminating other variables, the strength varies with the weight. In the present series, the exact dimensions of the test pieces were not always measured, so that this point was not definitely verified.

EFFECT OF HEIGHT OF TEST PIECE ON STRENGTH OF CONCRETE.

To compare the strength of test pieces of different length, especially for comparing the strength of cubes or cylinders whose length is equal to the diameter with cylinders having a length double the diameter. Prisms 4 in. square and another set 8 in. square were made up of lengths varying from half the width up to six times the width.

It is generally recognized that the shorter the test pieces, the greater the compressive strength. A few tests have been made in the past of neat cement and others of sandstone prisms, but no comparative records of concrete test pieces of different height are on record.

Table I gives the average results of the two series referred to above. To eliminate the variations due to local conditions, and to present the results in a form suitable for direct use, a curve is presented in Fig. 1,* where the ratios of strengths are shown, based on the strength of a prism whose length is double its width. The ratios are also given in figures in Table I.

If the ratios be expressed in terms of a cube, it will be seen that a test piece half the height of a cube is 50 per cent stronger than the cube, while a prism of double the height of a cube is about 73 per cent of the cube.

The variation in strength of test pieces of different height is due probably chiefly to the heads of the machine which confine the test piece. In actual construction, however, wherever the height is small in proportion to the width, there may be similar restraint.

Fig. 2 shows the average variation in strength of the individual test pieces from the mean strength of each group. In general, 5 to 15 per cent variation is to be expected. Inspection of the curve shows comparatively little difference in variation between

*Results from the University of California came too late to include, but agree in a general way with the curve.

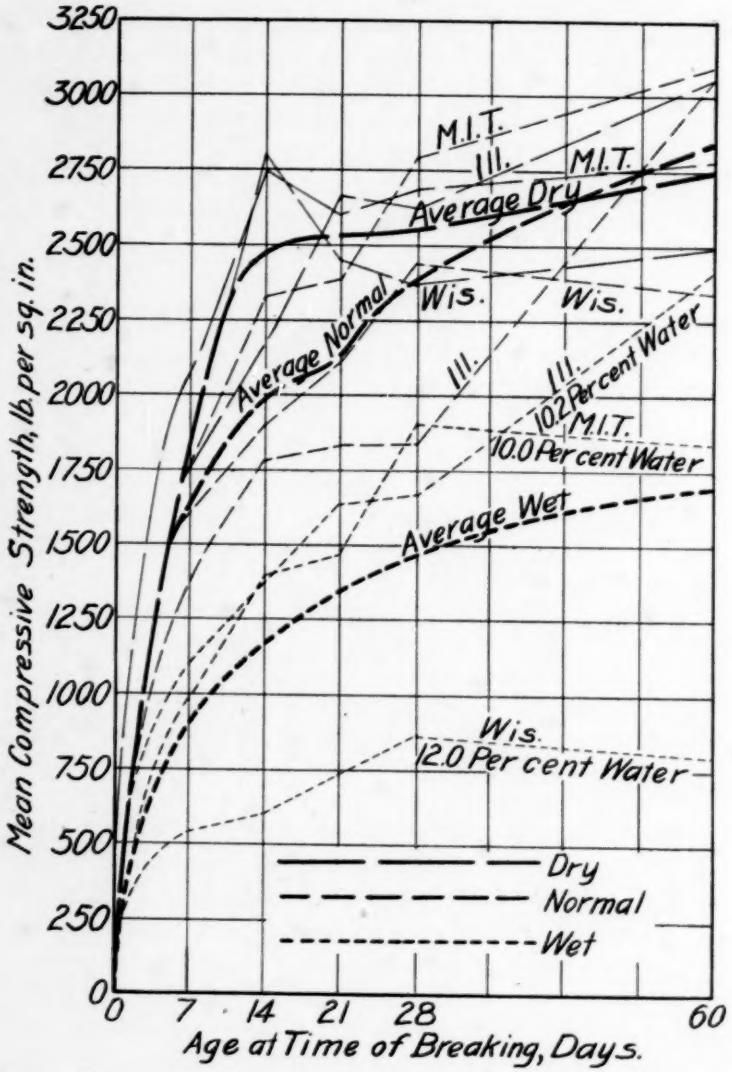


FIG. 5.—GROWTH IN STRENGTH OF CONCRETE OF WET, NORMAL AND DRY CONSISTENCIES. (SEE TABLE IV.)

Proportions about 1 : 2 : 4. Individual curves from each University and Composite Curves for each Consistency. Specimens 6 by 6 in. Cylinders. For Approximate Strength of 8 x 16 in. Cylinders divide values by 1.37.

lengths of $^{l}/_{d}=1$ (the cube) and $^{l}/_{d}=3$. More variation may be expected for both longer and shorter test pieces.

EFFECT OF SIZE AND SHAPE OF TEST PIECE UPON STRENGTH.

The relative strength of cylinders of different size is given in Table II. Fig. 3 gives similar results by ratios, based on an 8 by 8-in. cylinder, including test pieces having coarse aggregate of larger size. The curve shows more variation in the results of dif-

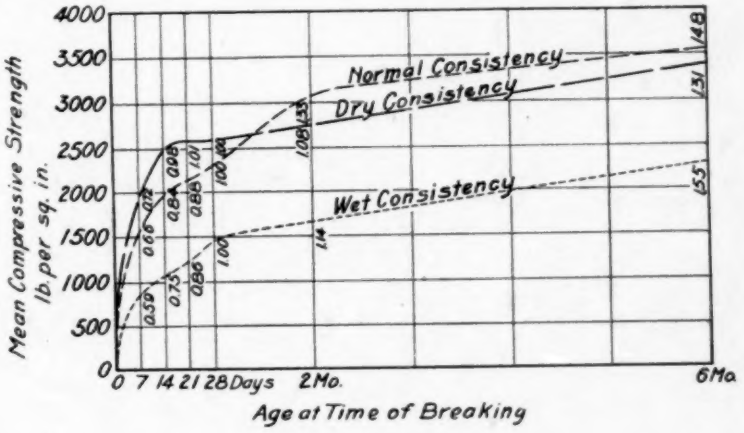


FIG. 6.—GROWTH IN STRENGTH OF CONCRETE OF WET, NORMAL AND DRY CONSISTENCIES.

6 x 6-in. cylinders; Proportions about 1 : 2 : 4. Made at University of Illinois, University of Wisconsin, Mass. Institute of Technology and University of California.

Figures on the curves indicate ratio of strength, based on strength at 28 days as 1.00.

For approximate strength of 8 x 16-in. cylinders divide values by 1.37.

ferent laboratories than in most of the series, but the curve indicates but little difference in compressive strength in test pieces ranging from 6 by 6 in. to 10 by 10 in.

A comparison of cylinders with cubes or prisms is given in Table III. The cube or square prism is slightly stronger, about 4 per cent on the average, than the cylinder whose diameter is equal to the side of the square. This may be due not so much to the variation in making the test piece as to the restraint of the heads of the machine.

EFFECT OF MAXIMUM SIZE OF AGGREGATE ON THE STRENGTH OF THE CONCRETE.

The results of tests of concrete made up with the same sand but coarse aggregates of different size are inconclusive, because of the lack of agreement between different laboratories. Two laboratories out of the three making these tests show an increase

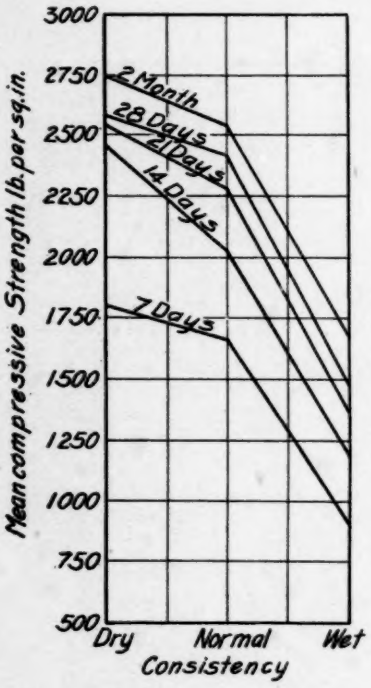


FIG. 7.—COMPARATIVE STRENGTH OF CONCRETE OF DIFFERENT CONSISTENCIES AT DIFFERENT AGES. (SEE TABLE IV.)

Compression tests of 6 x 6 in. concrete cylinders of Wet, Normal and Dry Consistencies at University of Illinois, University of Wisconsin, and Massachusetts Institute of Technology. Proportions about 1 : 2 : 4. Age 7 days to 2 months.

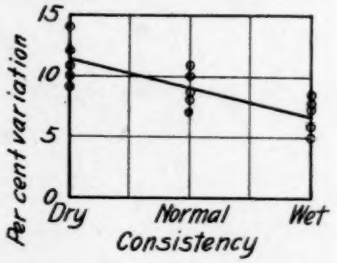


FIG. 8.—AVERAGE PER CENT VARIATION IN STRENGTH FROM THE MEAN OF EACH CONSISTENCY. (SEE TABLE IV.)

in the strength of the test piece with the increase in the size of coarse aggregate, and this is in line with the records of other tests.

The effect of the size of the coarse aggregate on the accuracy of the tests is indicated in Fig. 4. For 8 by 8 in. test pieces, and larger, the variation in strength of similar test pieces with

either sizes of stone is about the same. For 6 by 6 in. test pieces, the finer stone gives as uniform test pieces as the larger dimensions. For the 2-in. stone, the 6 by 6 in. test pieces are less

TABLE IV.—COMPARATIVE STRENGTH OF CONCRETE OF VARIOUS CONSISTENCIES AT DIFFERENT AGES. (See Fig. 5, 6, 7 and 8.)

Each Value is an Average of four 6-in. Cylinders. Proportions about 1 : 2: 4.

Age.	Average Compressive Strength, lb. per sq. in.											
	Univ. of Ill.*			Univ. of Wis.			Mass. Inst. Tech.			Univ. of Cal.†		
	Dry	Normal	Wet	Dry	Normal	Wet	Dry	Normal	Wet	Dry	Normal	Wet
7 days	1751	1390	1103	1690	1580	533	2047	1740	965	1083	724	521
14 days	2140	1775	1354	2795	1905	600	2742	2320	1372	1802	805	676
21 days	2658	1816	1623	2450	2095	722	2594	2396	1464	2182	1093	834
28 days	2615	1820	1657	2380	2430	860	2679	2882	1895	2413	1225	909
2 mo.	3056	3063	2410	2485	2340	787	2761	3092	1830	2659	1560	1157
6 mo.	3941	3431	3281	3375	3860	1451	....	....	....	3485	2145	1304

NOTE.—To convert strengths to basis of 8 x 16 in. clyinder divide values by 1.37.

*Tests at one year reported since Convention give: Dry, 3700 lb; normal, 3768 lb., wet 3760 lb.

† This column not included in average curves because of difference in the conditions.

TABLE V.—COMPARATIVE STRENGTH OF CONCRETE AT DIFFERENT AGES AND CONSISTENCIES STORED UNDER DIFFERENT CONDITIONS.

Each Value is an Average of four 6-in. Cylinders. Proportions 1 : 2 : 4 by weight. Normal Consistency.

Tests at University of Illinois.

Consistency.	Water in Mixing, %	Storage.	Compressive Strength at Different Ages, lb. per sq. in.						
			7 days.	14 days.	21 days.	28 days.	2 mo.	6 mo.†	1 year†
Dry.....	8.4	Damp sand..	1751	2140	2658	2615	3056	3941	3700
Normal..	9.3	Damp sand..	1390	1775	1816	1820	3063	3431	3768
Wet.....	10.2	Damp sand..	1103	1354	1623	1657	2410	3281	3760
Normal..	9.3	Air.....	1481	2061	2126	2116	2232	2049	2350
Normal..	9.3	Coated with paraffine.... Damp sand..	....	....	....	2314	2521	3339	3675
Normal..	9.3	Damp sand*.	....	....	....	....	2734	3433	3945
Normal..	9.3	Air†	....	....	....	....	2208	1888	2000

*Made from dry stone; for all other test pieces the stone had been thoroughly wet before mixing.

† Tests reported since Conventon.

accurate, and for the 4 by 4 in. test pieces there is greater variation for all sizes of aggregate. Stone having a maximum size of $\frac{3}{4}$ in. is included in the lower curve.

GROWTH IN STRENGTH OF CONCRETE.

The growth in strength of concrete for ages ranging from seven days to two months is given in Table IV, for test pieces of different consistency. The results are shown graphically in Figs. 5 and 6.

EFFECT OF CONSISTENCY UPON THE STRENGTH OF CONCRETE.

The results of tests of test pieces made with different percentages of water correspond to results of other tests on record. The tests show lower strength as the percentage of water is increased. The strengths obtained by the different colleges are

TABLE VI.—COMPARATIVE STRENGTH OF CONCRETE WITH FORMS REMOVED AT DIFFERENT PERIODS.

Each Value is an Average of five 6-in. Cylinders.
Proportion about 1 : 2 : 4 by weight. Normal Consistency.
Tops and bottoms of Test pieces paraffined after making. Age 3 months.

Tests at University of Illinois.

Treatment of Ends of Test Piece.	Forms and Paraffine Removed at Age of	Storage after Forms Removed.	Compressive Strength at Age of 3 months, lb. per sq. in.
No paraffine	1 day	Air	1978
Paraffine	7 days	Air	2343
Paraffine	30 days	Air	3166
Paraffine	90 days	Tested damp	2806

shown in Table IV. In Fig. 5 the results are plotted, and to still better compare the consistency, Fig. 7 gives the curves arranged in the other way.

Slightly less variable results are shown by Fig. 8 to be attained with the wet mix. However, Fig. 5 shows greater variation between different laboratories, so that the normal consistency test pieces are best for comparison.

STORAGE OF TEST PIECES.

The University of Illinois stored the test pieces for their regular tests in damp sand. To compare the effect of different methods of storage, test pieces were placed in damp sand, air,

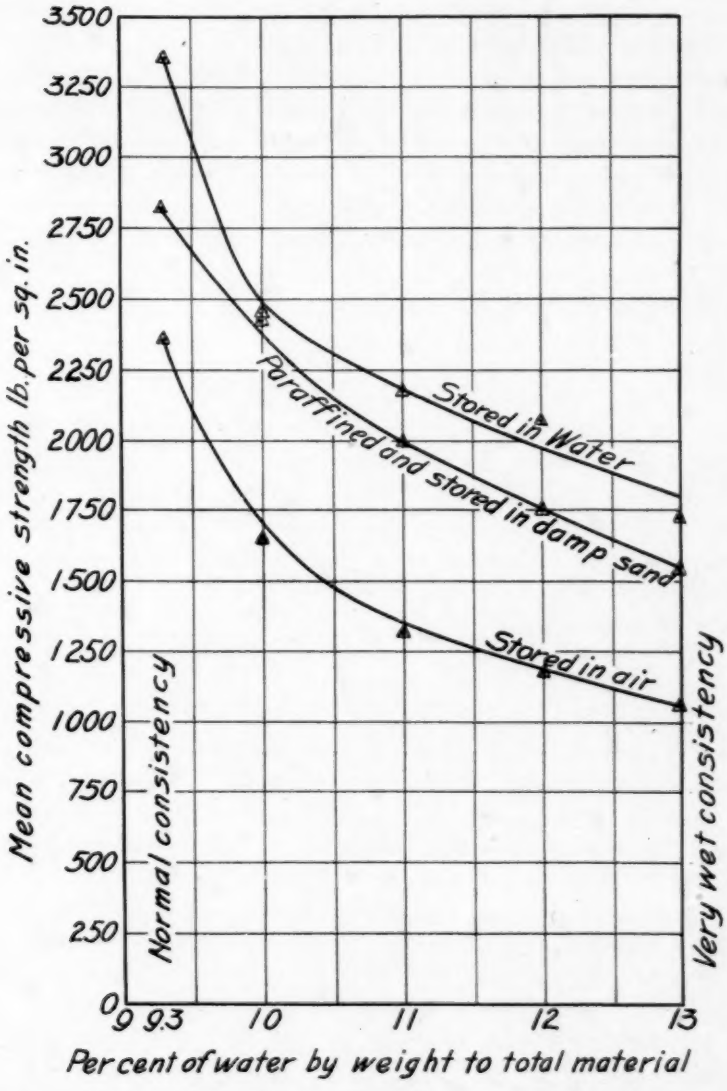


FIG. 9.—EFFECT OF DIFFERENT PERCENTAGES OF WATER UPON THE STRENGTH OF CONCRETE WITH DIFFERENT METHODS OF STORAGE.

Age 3 months. Proportions about 1 : 2 : 4. Each point is an average of five 6-in. cylinders.

Tests at University of Illinois.

water, and in damp sand after having been coated with paraffine. Table V gives a comparison of the results for different consistencies and at different ages.

Table VI presents a short series showing the effect of retaining the moisture in the test pieces for different periods by keeping the test pieces in the form for different lengths of time, while the heads are coated with paraffine.

Curves are shown in Fig. 9 giving the comparative effect of different methods of storage on concrete made with different percentages of water.

TESTS OF BEAMS OF PLAIN CONCRETE.

The University of Illinois made up 10 plain concrete beams 6 by 8 in. in section for transverse tests. The proportions were the same that they used in all the rest of the test pieces.

The beams were loaded at the one-third point of a 3-foot span, the 8 in. dimension being vertical. The modulus of rupture at the age of 3 months varied from 684 to 844 lb. per sq. in., with an average of 775 lb. per sq. in.

NEED OF SPECIAL INVESTIGATION OF SAND.

To properly carry on an investigation of sand which cannot be satisfactorily handled by scattered laboratories, there is need of a special investigator who can take up the problem in a thorough and scientific manner. Nearly every day cases are brought to notice of defective and inferior concrete, made from sand good in appearance but containing certain almost invisible deleterious material which prevents the proper hardening of the concrete. Only by a carefully thought out and extended series of tests, both chemical and physical, of natural sands of good and bad quality can the problems of the selection of sand for mortar and concrete be solved. There also should be found means for treatment of sands of poor quality to make it possible to use them under certain conditions. These questions are as important as any confronting the art of concrete and reinforced concrete construction.

Such an investigation will require funds, and the Committee is considering means for obtaining the necessary sum for the purpose.

Respectfully submitted,

SANFORD E. THOMPSON, *Chairman.*
CLOYD M. CHAPMAN, *Secretary.*
RUSSELL S. GREENMAN.
WILLIAM M. KINNEY.
ARTHUR N. TALBOT.
GUY WISE.

APPENDIX. DIRECTIONS FOR TESTS.

Materials.

Cement.—Select a brand of cement or a mixture of brands of standard reputation.

Keep cement in a cool, dry place to avoid change in setting properties. Discard any cement that is lumpy, or that has a flash set, *i.e.*, stiffens while mixing.

Sand.—Select a good concrete sand, well graded, and of medium coarseness. Provide enough sand at the start for all tests, mix it together by shoveling, and store in a dry place. If sand contains moisture, it must be corrected for in weighing out the proportions and in weighing the water in mixing.

Stone.—Prepare all the stone in advance to have it absolutely uniform.

Use preferably trap, hard limestone (which cannot be shaved with a knife), marble, or granite.

Molds.—Prepare molds, which may be either wood, iron, or steel.

Bottomless molds may be used if preferred, provided they are set to avoid leakage.

For cylinders, No. 12 gauge metal may be rolled to shape in any plumber's shop, and the joint made tight. If wood molds are used, soak thoroughly with water.

Coat either steel or wood molds with crude petroleum oil or a similar heavy oil.

Consistency.—To determine consistency for aggregate up to $\frac{3}{4}$ in. in size, take a metal cylinder slightly tapering 3 in. in diameter and 6 in. high. Grease inside of cylinder. Mix up a batch of concrete, using the materials to be used in the tests and place in cylinder compacted slightly. Remove cylinder. If concrete slumps, repeat test using less water. If concrete does not slump, repeat test using more water. Normal consistency suitable for making laboratory tests of concrete is determined by the percentage of water used when the cylinder shows a slight tendency to slump, but does not appreciably increase in diameter. It may settle very slightly in height.

Same actual quantity of water must be used in all duplicate test pieces.

Proportions.—Use proportions 1 : 2 : 4 by weight for all tests.

Mixing.—Concrete is most readily mixed in a tray or on a large piece of sheet metal.

A separate mix must be made for each individual test piece. Tests indicate that otherwise there is a variation in the proportions in different test pieces which affects the results.

Mix sand and cement dry. Spread stone in uniform layers. Spread mixed sand and cement on stone in uniform layer. Mix dry twice. Pour water and mix at least three times. In mixing, as in concrete work, one shovels starting at one edge of the layer and working across.

Leave concrete in molds a definite time, probably three days.

Record temperature of room, keeping as uniform as possible.

Wet each test piece on removal from mold.

Store in damp sand or under damp cloths to prevent drying out.

Before crushing, measure volume of each test piece.

Before crushing, weigh each test piece.

State method used in crushing to distribute the stress on the surface.

It will be advisable also both on account of the value of the results and the benefit to the student to compute the density of a few representative test pieces. To do this, the specific gravity of the material must be found. The method described in Taylor and Thompson's *Concrete, Plain and Reinforced, 2d Edition*, may be used in this determination.

It is desirable, although not absolutely necessary, since comparative results are the aim, to make tensile tests of the cement and of the sand mortar used in the tests.

SERIES 1. COMPARATIVE TESTS TO DETERMINE VARIATION IN STRENGTH DUE TO THE SIZE OF THE SPECIMEN, USING DIFFERENT SIZED AGGREGATES.

This series contains 60 test pieces. If this is too many, omit one or two of the sizes.

With each size of stone, make:

4	cylinders	4	in.	diameter	by	4	in.	high
4	"	6	"	"	"	6	"	"
4	"	8	"	"	"	8	"	"
4	"	10	"	"	"	10	"	"
4	"	12	"	"	"	12	"	"

Make all these test pieces with each of the following stones:

(*a*) Stone which has passed a $\frac{3}{4}$-in. laboratory screen, round holes, and retained on $\frac{1}{2}$-in. screen.

(*b*) Mixture of stone, one part of which has passed a $1\frac{1}{4}$-in. and is retained on a 1-in., and one part of which has passed a $\frac{3}{4}$-in. and been retained on a $\frac{1}{2}$-in. screen.

(*c*) Mixture of 2 stones in equal parts, one part between 2 in. and $1\frac{1}{2}$ in. and the other part between 1 in. and $\frac{3}{4}$ in.

In making up these test pieces, since the comparison is between sizes of test pieces and of stones, it will be best, since they cannot all be made at the same time, to make them in the following order:

One test piece each of each size with the (*a*) stone; next, one test piece each with the (*b*) stone; next, one test piece each with the (*c*) stone; next, repeat this series for the 3 other test pieces of each size and kind of stone.

Test all test pieces at three months.

SERIES 2. COMPARATIVE TESTS TO DETERMINE THE VARIATION IN STRENGTH DUE TO THE HEIGHT OF TEST PIECES.

Use proportions 1 : 2 : 4 by dry weight.

Use stone passing $\frac{3}{4}$ in. and retained on $\frac{1}{2}$-in. holes for all test pieces.

Make all test pieces 6 in. cylinders 6 in. high.

Use "normal consistency" described.

This series contains 32 test pieces as follows:

4	prisms	4	in.	square	by	2	in.	high
4	"	4	"	"	"	3	"	"
4	cubes	4	"	by 4 in.				
4	prisms	4	in.	square	by	6	in.	high
4	"	4	"	"	"	8	"	"

4 prisms 4 in. square by 12 in. high.
4 " 4 " " " 16 " "
4 " 4 " " " 24 " "

Crush all test pieces at the age of 3 months.

To best compare sizes, make up first one test piece each of each size and then repeat 3 times.

SERIES 3. COMPARATIVE TESTS TO DETERMINE THE VARIATION IN STRENGTH DUE TO HEIGHT OF TEST PIECES.

Use proportions 1 : 2 : 4 by dry weight.

Use stone passing $\frac{3}{4}$ in. and retained on $\frac{1}{2}$ in. holes for all test pieces.

Use "normal consistency" described.

This series contains 28 test pieces as follows:

4 prisms 8 in. square by 4 in. high
4 " 8 " " " 6 " "
4 " 8 " " " 8 " "
4 " 8 " " " 12 " "
4 " 8 " " " 16 " "
4 " 8 " " " 24 " "
4 " 8 " " " 32 " "

Crush all test pieces at the age of 3 months.

To compare sizes, make up one test piece each of each size, and then repeat this 3 times.

SERIES 4.—COMPARATIVE TESTS OF STRENGTH OF CYLINDERS VS. CUBES AND PRISMS.

Use stone passing $\frac{3}{4}$ in. holes and retained on $\frac{1}{2}$ in. for all test pieces.

Use proportions 1 : 2 : 4 by dry weight.

Use "normal consistency" described.

This series will contain 32 test pieces, as follows:

4 cubes 6 by 6 in.
4 cylinders 6 in. diameter by 6 in. high
4 cubes 8 by 8 in.
4 cylinders 8 in. diameter by 8 in. high
4 prisms 8 in. square by 16 in. high

4 cylinders 8 in. diameter by 16 in. high
4 prisms 6 in. square by 12 in. high
4 cylinders 6 in. diameter by 12 in. high

Provide one each of the different size molds.

Make these test pieces up one each in the order given, then repeat three times to make 4 test pieces of each size.

Test all test pieces at three months.

SERIES 5.—GROWTH IN STRENGTH USING DIFFERENT CONSISTENCIES.

Use proportions 1 : 2 : 4 dry weight.

Use stone passing $\frac{3}{4}$ in. holes and retained on $\frac{1}{2}$ in. for all test pieces.

Use three consistencies as follows:

Dry.—Concrete just wet enough so that a thin skin of mortar will rise to the top on ramming.

Plastic or Normal.—Consistency described above as normal.

Wet.—Soft enough so that the mortar in the concrete will almost flow and so that the concrete requires no ramming in placing. This consistency is about like ordinary building material work.

Make all test pieces as cylinders 6 in. in diameter and 6 in. high.

Make 24 test pieces of each of the three consistencies.

Crush 4 test pieces of each of the 3 consistencies (*i.e.*, 12 test pieces in all) at each of the following periods:

7 days
14 "
21 "
30 "
60 "
6 months

(These periods may be extended further if the conditions warrant making of more test pieces. Also, if the test pieces test very uniformly, 3 may be broken for each average instead of 4.)

SOME COMPARATIVE CORROSION TESTS OF PLASTERED METAL LATH—A PROGRESS REPORT.

By J. C. Pearson.*

About three years ago the Bureau of Standards was requested by the Associated Metal Lath Manufacturers to co-operate with them in determining what factors play the most important part in bringing about the corrosion and consequent failure of metal lath under stucco and plaster.

At that time it was represented that failures of metal lath were sufficiently frequent to be a matter of concern to the lath industry, and that many were openly condemning the use of this material on the ground that its tendency to corrosion rendered it unsuitable for permanent construction. Reliable data were not at hand on the relative value of protective coatings for the lath itself, nor on the corrosive properties of different plasters, nor on the best methods of construction for the preservation of the lath. Information was needed on these points, not only by the lath manufacturers but by all interested in building materials.

The Bureau of Standards was at that time conducting corrosion investigations along certain lines, and it was felt that the program might readily be enlarged to include a series of comparative tests on the corrosion of metal lath. Recognizing, however, that the public might have an unusual interest in such tests, in view of the increasing popularity of stucco construction, the Bureau signified its willingness to undertake this work, not as a private test but as a part of its investigative work, with the understanding that the results should be available to the public. The lath manufacturers not only concurred in this arrangement but also agreed to provide all samples of lath required for the tests.

Purpose and Program of Tests.

In developing the plans for the tests it was proposed that the chief aim and purpose of the work should be, as already indicated:

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1. To determine the relative protective value of various coatings for the metal lath as compared with their actual cost.

2. To compare the corrosive properties of various types of plaster.

3. To determine whether ordinary methods of construction are adequate to insure the durability of the lath, and to investigate other methods.

A preliminary program was also laid out, the essential features of which were as follows:

First. The tests should be primarily qualitative, comparative corrosion tests of metal lath, embracing as many different varieties of mesh, coating, etc., as possible.

Second. The samples of lath should be erected in panels and plastered with a number of different plasters typical of those in common use.

Third. The lath should be supported in such manner that the backs of the panels should be open to view. Thus the progress of corrosion could be followed until it was deemed advisable to examine the condition of the metal actually imbedded in the plaster.

Fourth. It was decided moderately to accelerate the normal exposure by sprinkling the exterior walls during the summer months, and by having the interior panels exposed at all times to the out-of-door atmosphere but directly sheltered from the weather.

This program, as applying to the panels included in the original plans, was adhered to without change. A few of the panels, however, were erected with a modification of the open back construction, which led to an extension of the work to include two other types of construction. These additional panels will be referred to later.

The present report is limited to a description of the tests and a statement of the condition of the lath after two years' exposure. As the progress of corrosion has proven to be slower than was anticipated, it has seemed best to wait, probably another year, before examining the condition of the lath actually imbedded in the plaster. The report, therefore, is based only on the appearance of the exposed metal and does not necessarily indicate the exact status of the tests.

CONSTRUCTION OF THE PANELS.

A suitable location for the panels was found at the east end of a storage building on the brow of the hill south of the Bureau's Engineering Laboratory. In this manner a north, east and south exposure was obtained for the exterior panels, whereas the interior panels were erected on partitions parallel to the north and south walls, inside the latter and abutting on the east wall. The dimensions and general appearance of the walls and partitions

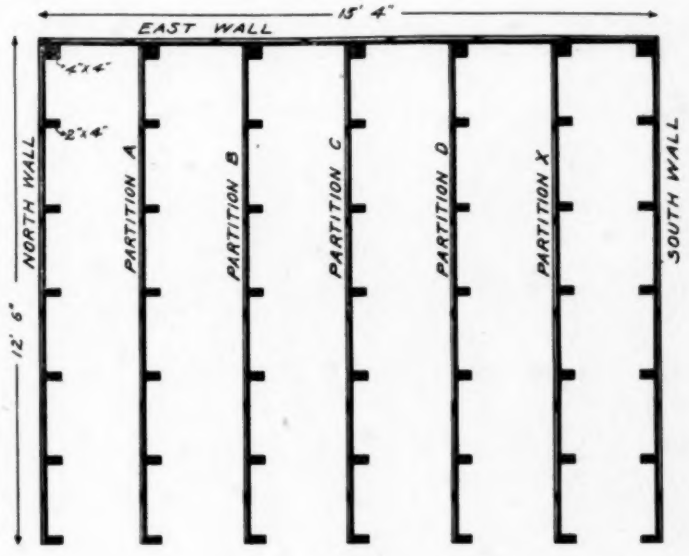

FIG. 1.—PLAN OF WALLS AND PARTITIONS CARRYING PANELS.

carrying the panels can be obtained from the layout plan, Fig. 1, and the photographs, Fig. 3 and 4. The exterior panels number 132, of which 119 are nearly the regulation size, 18 x 24 in., the remaining 13 being somewhat less than half this size and added to fill up an otherwise empty space. Some of the smaller panels may be seen just at the left of the door in Fig. 3. The interior panels number 150, all of which are practically full size.

The construction of the panels is shown in Fig. 2. By mounting the lath on strips, as shown, furring was not required and more than three-quarters of the panel was left exposed on the

back, thus affording access for examination of the key of the plaster and the condition of the metal.

Some criticism has been offered of thus having the lath exposed, on the ground that very little actual construction would permit such a free circulation of air and moisture at the back of the lath. It was felt, however, that if results were to be obtained within a reasonable period, say not over five years, some method of moderately stimulating corrosion must be adopted which would not be open to the criticism of highly accelerated laboratory tests; and no better method suggested itself. Further, as already

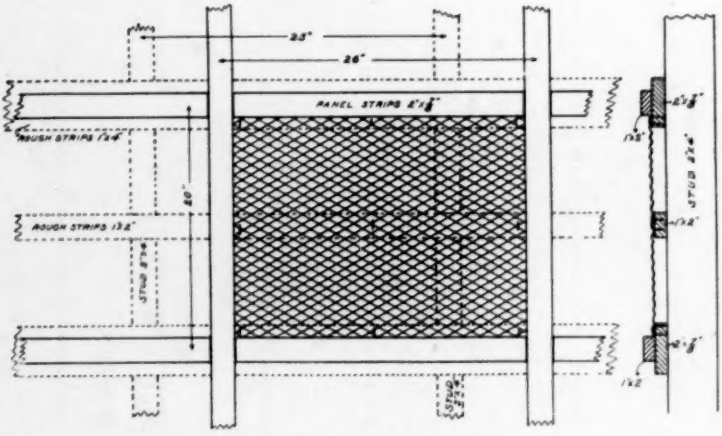

FIG. 2.—PLAN OF PANEL CONSTRUCTION.

stated, the open back construction served the double purpose of helping matters along and at the same time allowing one to see what was going on.

MATERIALS FOR THE TESTS.

In the selection of the materials for the tests we were especially indebted to Mr. H. B. McMaster, Commissioner of the Publicity Bureau of the Associated Metal Lath Manufacturers, for providing the samples of metal lath, and to Mr. W. W. Shearer of the Rosslyn Supply Company of Washington, D. C., for assistance in selecting and procuring the types of plaster. To

the latter also the writer was especially indebted for much valuable advice during the progress of construction of the panels.

For convenience in referring to the samples of lath used in the tests they will be considered as divided into "types," "classes," and "varieties." Thus laths may be regarded as being of the same type when they have the same form of mesh, of the same class when they have the same kind of protective coating, but of the same variety only when they are identical in

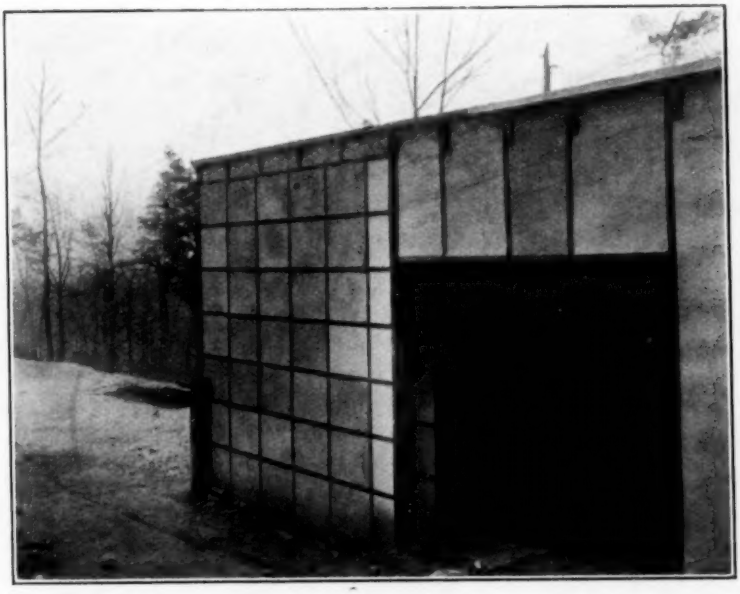

FIG. 3.—VIEW OF THE PANELS FROM THE NORTHWEST, SHOWING THE INTERIOR PARTITIONS.

every respect. Different metals also constitute separate classes, as plain steel and ingot iron, but no distinction has been made thus far between the varieties of steel.

The samples of lath actually used in the tests were of 39 varieties contributed by eight manufacturers. Among these there were 9 types and 7 classes, as above defined. The expanded metal lath was for the most part 24 gauge, weighing 3 lb. or more to the square yard. A few special types of stamped

lath were also included which are generally heavier than the expanded lath.

Table I gives a complete list of the samples of lath used in the tests.

TABLE I.—LIST OF THE VARIETIES, TYPES, CLASSES AND MANUFACTURERS OF THE METAL LATH USED IN THE CORROSION TESTS.

Sample No.	Type.	Class.	Number of Panels.	Manufacturer.
1	Truss-loop	Painted	6	Bostwick Steel Lath Company.
2	"	Galv. (before exp.)	4	" " " "
3	Diamond	Painted	10	" " " "
4	"	Galv. (before exp.)	7	" " " "
5	Herringbone	Plain	14	General Fireproofing Company.
6	"	Painted	6	" " "
7	"	Galv. (before exp.)	6	" " "
8	"	Sherardized	8	" " "
9	"	Plain ingot iron	12	" " "
10	"	Painted " "	8	" " "
11	Boston	Plain	6	" " "
12	"	Painted	7	" " "
13	Key	Plain	7	" " "
14	"	Painted	8	" " "
15	"	Galv. (after exp.)	6	" " "
16	Cup	Plain (anti-rust)	13	Sykes Metal Lath and Roofing Company.
17	"	Painted	6	" " " " " "
18	"	Galv. (before exp.)	6	" " " " " "
19	Modified Diamond	Plain	10	Consolidated Exp. Metal Companies
20	Diamond	"	10	" " " " "
21	Kno-burn	"	9	Northwestern Exp. Metal Company
22	"	Painted	4	" " " "
23	"	Galv. (after exp.)	5	" " " "
24	Cup	Plain	5	Gary Iron and Steel Company
25	"	Painted	2	" " " " "
26	"	Galv. (before exp.)	5	" " " " "
27	Diamond	Plain	11	Eastern Exp. Metal Company
28	"	Painted	8	" " " "
29	Emco	Plain	14	" " " "
30	"	Painted	9	" " " "
31	Modified Diamond	Plain	8	" " " "
32	" "	Painted	8	" " " "
33	" "	Galv. (before exp.)	6	" " " "
34	Corrugated Diamond	Painted	5	Youngstown Iron and Steel Company
35	" "	Galv. (after exp.)	4	" " " " "
36	" "	Sherardized	5	" " " " "
37	" "	Painted	5	" " " " "
38	" "	Galv. (after exp.)	3	" " " " "
39	" "	Sherardized	6	" " " " "

The foregoing list does not include all the varieties of lath submitted, some of which had to be omitted on account of lack of space. One or two manufacturers also submitted samples too late to be included in the tests as planned, and such samples have been thus far used only in supplementary tests, which will be very briefly described at the close of this paper.

All the labor involved in erecting the partitions, laying out the panels, and putting the lath in place, was done by regular

employees at the Bureau. As no plasterers were available, however, this part of the work was let out by contract. Practically all the plastering, both exterior and interior panels, was done by skilled workmen, the Bureau's only part in this being to specify what particular mixture should be applied to any given group of panels. Both exterior and interior plastering was two coat work, the second and finishing coat being for the most part sand or rough floated.

In the selection of plasters it was the aim to include only such types as were in common use. The mixtures, however, were arbitrarily chosen, and in a number of cases were not comparable with those used in practice. Therefore, the results obtained in these cases should not be considered as necessarily in accord with the comparative results which would be observed in other mixtures.

A complete list of the plasters used, the proportions of their ingredients by volume, and their distribution, is given in Table II.

TABLE II.—LIST OF THE PLASTERS APPLIED TO THE PANELS OF METAL LATH, AND THEIR DISTRIBUTION.

Plaster.	Proportions by Volume.	Number of Panels.	Location.
1. Cement, Ca. hyd. lime, sand	3/4 : 1/4 : 3	83	North and east walls
2. Cement, Mg. hyd. lime, sand	3/4 : 1/4 : 3	15	South wall
3. Alea lime, sand	1 : 2	11	" "
4. Alea lime, sand	1 : 4	15	" "
5. Cement, slaked lime, asbestic	1/2 : 1/2 : 2	8	North Wall
6. Mg. hyd. lime, cement and sand	1/2 : 1/2 : 2	15	Partition A
7. Ca. hyd. lime, cement and sand	1/2 : 1/2 : 2	15	" A
8. Mg. hyd. lime and sand	1 : 2	15	" B
9. Ca. hyd. lime and sand	1 : 2	15	" B
10. Keene's cement, hyd. lime, sand	1/4 : 1/4 : 3	20	" C
11. King's Windsor and sand	1 : 2	10	" C
12. Ivory and sand	1 : 2	10	" D
13. Ivory, wood fibered, neat		5	" D
14. Acme, wood fibered, neat		4	" D
15. Acme and sand	1 : 2	11	" D
16. Slaked lime, cement and sand	3/4 : 1/4 : 2	6	" X
17. Slaked lime, sand	1 : 2	6	" X
18. Alea lime, sand	1 : 2	6	" X
19. Slaked lime, asbestic	1 : 2	6	" X
20. Special, ready mixed		6	" X

NOTE.—It has been suggested that mixes 1 and 2 are slightly oversanded, and that mixes 4, 8, 9 and 10 are considerably oversanded, as compared with the proportions used in common practice.

It is also understood that on metal lath the first coat, especially in the case of lime mixtures, should be richer than the second and finishing coats. In these tests, however, the first

and second coats are the same throughout, except for the omission of hair from the second coat. Thus the interior mixtures which are regarded as oversanded, are oversanded only with respect to the scratch coat. This is evidenced by a number of badly cracked panels covered with the richer lime mixtures, and by the excellent condition of the plaster in the Keene's cement and lime panels.

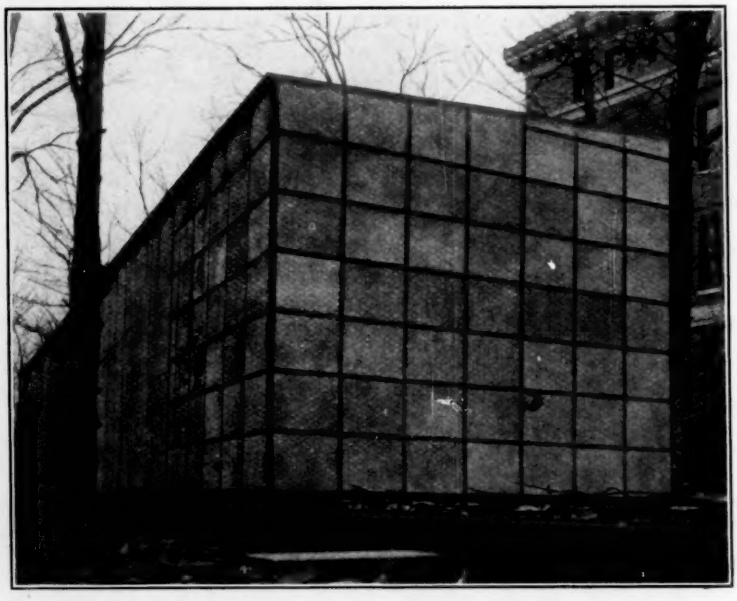

FIG. 4.—VIEW OF THE PANELS FROM THE SOUTHEAST.

The magnesia lime referred to in Table II is finishing lime comparatively high in magnesia, and would not ordinarily be used in scratch or brown coats. It was included to see whether any appreciable difference could be detected in corrosive action as compared with hydrated high calcium lime or ordinary slaked lime. For the same reason also it was used in the exterior stucco. The plaster designated as "Special" is a gypsum plaster treated in some manner to eliminate its corrosive action. It was included at the special request of the manufacturers and may probably be considered typical of its kind.

TREATMENT AND INSPECTION.

As indicated in the original program the only deliberate attempt to accelerate the tests was to sprinkle the exterior stucco panels two or three times a week, depending upon the weather, during the warmer half of the year. This program was carried out during the summer of 1912 and during the summer of 1913, until July. Three complete inspections and records have been made of the condition of the panels, and the status of the tests as presented in this progress report is based on the inspection of October, 1913.

RATING.

It is very difficult to establish a system of rating to indicate the condition of the lath. Some types of lath are covered almost entirely by the key of the plaster, others are nearly all exposed on the back. In some cases the rust is fairly vigorous and local, in others it is less vigorous but generally distributed. After some consideration the following scheme was adopted, not as an exact system of rating, but rather for descriptive and approximately comparative purposes:

10 indicates perfect condition, no rust.
9 indicates traces of rust only, in which no appreciable percentage area of the lath is affected.
8 indicates that about $\frac{1}{4}$ of the exposed metal surface is rusted.
7 indicates about $\frac{1}{2}$ of the exposed metal is rusted.
6 indicates about $\frac{3}{4}$ of the exposed metal is rusted.
5 indicates that all the uncovered surface is rusted.

Thus a rating of 9 or better indicates practically perfect condition. Numbers below 5 indicate only very roughly the advanced stages of corrosion. Thus 4 indicates that the rust is beyond the surface state and visibly eating into the lath, and 0 indicates practically complete failure of the lath. In only comparatively few cases has it been found necessary to estimate conditions below 5. These numbers have also been supplemented by notes on the general appearance of the rust if in any way worthy of remark. While the averages represented by the ratings are not necessarily indicative of the true condition of the lath on its road to failure, no simpler method has suggested itself of

describing the approximate status of the tests, and the averages probably represent the actual conditions quite close enough for purposes of comparison.

PRESENT STATUS OF THE TESTS.

It will be sufficient to present here a tabular summary of the data taken from the records of the October inspection, see Table III. In this table the average ratings of the different classes of lath are tabulated in order of excellence from left to right. The plasters are listed in the order of their apparent protective effect on the plain steel lath, this class being the largest and probably showing more pronounced effect than the others. The order is seen to be essentially the same for all classes of lath.

It must be remembered that at the present time it is not known what is going on underneath the plasters, so that conclusions based on the results presented in Table III are to be

TABLE III.—CONDITION AND NUMBER OF PANELS OF EACH CLASS OF METAL LATH UNDER THE DIFFERENT TYPES OF PLASTER.

	Plaster.	Galv. after Expansion.		Galv. before Expansion.		Painted Ingot Iron.		Painted Steel.		Sherardized.		Plain Ingot Iron.		Plain Steel.	
		Rating.	No.	Rating.	No.	Rating.	No.	Rating.	No.	Rating.	No.	Rating.	No.	Rating.	No.
	Exterior panels.														
1	¾ c, ¼ Ca. h.l., 3 s	10.0	6	9.8	11	8.6	4	8.6	25	8.9	9	6.9	4	5.8	24
2	½ c, ½ s.l., 2 asb	....	..	....	..	....	..	8.5	8	....	..	....	..	....	..
3	¾ c, ¼ mg.hy.l., 3 s	10.0	1	9.8	3	....	..	8.3	5	8.2	2	7.5	1	5.0	3
4	1 Alca, 2 sand	9.5	1	9.0	1	....	..	8.1	6	7.0	1	....	..	5.0	2
5	1 Alca, 4 sand	9.0	1	8.5	2	7.0	1	6.6	5	6.0	1	....	..	3.8	5
	Average	9.8	9	9.6	17	8.3	5	8.3	49	8.4	13	7.0	5	5.4	34
	Interior panels.														
6	1 Alca, 2 sand	....	..	....	..	....	..	....	..	....	..	....	..	9.0	6
7	1 s l., 2 sand	....	..	....	..	....	..	....	..	....	..	....	..	8.5	6
8	¾ Ca.hy.l., ¼ c, 2 s	10.0	1	10.0	2	....	..	9.2	6	....	..	....	..	8.2	6
9	Special	....	..	....	..	....	..	....	..	....	..	....	..	8.2	6
10	1 K.W., 2 sand	....	..	9.5	2	9.0	1	9.2	2	7.5	1	....	..	8.1	4
11	1 Ca.hy.l., 2 sand	10.0	1	9.8	2	....	..	9.2	4	10.0	1	9.5	1	7.6	6
12	¾ s.l., ¼ c, 2 s	....	..	....	..	....	..	....	..	....	..	....	..	7.6	6
13	¾ mg.hy.l., ¼ c, 2 s	10.0	2	9.5	1	9.5	1	9.3	5	....	..	7.5	1	7.5	5
14	1 s. l., 2 asb	....	..	....	..	....	..	....	..	....	..	....	..	7.3	6
15	1 Ivory, 2 s	10.0	2	9.8	2	....	..	8.9	5	....	..	7.0	1	7.2	5
16	1 Acme, 2 s	10.0	2	9.5	2	....	..	8.9	5	....	..	7.5	1	7.1	5
17	1 Mg.hy.l., 2 s	10.0	1	9.8	2	....	..	9.0	4	9.0	1	6.5	1	6.4	6
18	¼ K, ¾ h.l., 3 s	....	..	9.2	4	9.5	1	9.0	4	7.8	3	5.5	2	5.7	6
	Average	10.0	9	9.6	17	9.3	3	9.1	35	8.3	6	7.0	7	7.6	73
	Total Average	9.9	18	9.6	34	8.7	8	8.6	84	8.4	19	7.0	12	6.9	107

NOTE.—It has been suggested that mixes 1 and 3 are slightly oversanded and that mixes 5, 11, 17 and 18 are considerably oversanded, as compared with the proportions used in common practice.

regarded as tentative only, pending later developments. Examination of the table will show that the condition of the lath under the three representative brands, King's Windsor, Ivory and Acme, is almost exactly a general average condition of all the interior panels. That is, the corrosive action of the straight gypsum plasters appears to be less vigorous than was anticipated. The oversanded condition of the plasters containing the high calcium hydrate, the magnesium hydrate, and the Keene's cement may account in part for their low average rating, which in their proper relation to the other plasters would probably raise the general average, and lower the relative position of the gypsum group.

On the exterior walls all the cement stucco panels are in fairly good condition, whereas the Alca lime panels are already beginning to fail. In fact, the exterior Alca panels are generally in worse condition, both on the face and back, than the figures indicate. This condition is probably due in part to the use of too lean mixtures. The 1:4 and 1 : 2 volume mixtures are approximately 1 : 9 and 1 : 4.5 weight mixtures, neither of which is quite as rich as the 1 : 3.5 weight mixture specified by the manufacturers for the first coat and 1 : 4 for the second coat. Another condition might also have contributed to the low rating of the panels, viz: some of them are situated on the south wall near the end, which, as already stated, was left open for a few months after erection. Consequently in the case of severe storms the backs of some of these panels may bave been exposed to moisture during this period more than subsequently. Therefore these results should be considered with caution until richer mixtures have been tested.

Comparing the various classes of lath, it is seen that the galvanized lath is unquestionably in the best condition. There is also very little choice between the lath galvanized after expansion and that cut from galvanized sheets, nearly all samples of both classes being in practically perfect condition. It is believed that this is in accord with the theory of galvanized coatings, and probably a number of years will pass before any of the galvanized lath in durable plaster or stucco shows indications of failure.

The painted lath are in surprisingly good condition as shown by the fact that their average rating is higher than that of the

Sherardized lath. Some one has suggested that the painted lath may have been more carefully prepared for these tests than they are for the "trade." Possibly this may be true in some cases, but the same suggestion applies equally well to the other classes of lath, and in justice to the manufacturers who submitted the samples, it may be stated that the only suspected variety of this class shows a condition of 8.6, which is exactly the average of all the painted lath together.

The Sherardized samples do not bear out the claims that are made for this coating. While most of the samples are in good condition, some of them are rusting vigorously, and the rust seems to be increasing. This is not in accord with statements that the Sherardized zinc coating may show an apparent incipient corrosion which soon ceases. It may be noted, however, that some doubt has been expressed regarding the quality of these particular samples, and further disinterested tests of this material are required to establish its comparative efficiency in protection against corrosion.

Unfortunately there was no "Toncan" metal or copper bearing steel lath on hand at the time these tests were started. The samples of painted and plain ingot iron are at present in very slightly better condition than the painted and plain steel, respectively. It is hoped that these may all be included in subsequent tests, in order that more directly comparative results may be obtained.

Perhaps the most useful information resulting from these tests would be that obtained by comparison of the cost of the various classes of lath with their durability in any given plaster. But as the durability of the lath can now be only very roughly estimated, a comparison of this sort should be postponed until later. It is probable that some interesting data shall be obtained on this subject before these tests shall have been completed.

SUPPLEMENTARY TESTS.

In conclusion it is desired to describe very briefly some supplementary work in connection with these lath and plaster tests, from which, however, only preliminary results have been obtained.

During the winter of 1911 and 1912, 88 plaster blocks 6 in.

square by 1½ in. thick, were made up with 22 different plaster mixes, the majority of them containing varying proportions of cement and lime, and gypsum plaster and lime. Four blocks of each variety of plaster were made and in the center of each block was imbedded a 4½-in. square of plain steel lath. There were thus prepared four sets of blocks of 22 each. One of these sets was stored in an open cement box out-of-doors, the plan being to keep these partially immersed in water. Another set was stored in the damp closet, another in the comparatively dry air of the laboratory, and the remaining set was placed on a shelf over the partitions carrying the interior panels. It is the purpose to note the durability of these blocks and the condition of the metal at the time of failure, and at some future time to examine all that have survived the various treatments. Unfortunately a number of the blocks exposed to water, and many of those stored in air were accidentally destroyed during recent alterations in the laboratory. These will probably be replaced as soon as new materials can be obtained.

In the summer of 1912 samples of some 15 selected varieties of lath were exposed to the weather by suspending them on a cable in the rear of the Engineering Laboratory. Last summer these specimens with a number of new ones were mounted on a rack in nearly the same location, where the progress of corrosion may be qualitatively compared.

In the spring of 1912, 35 additional panels were added on the south wall of the storage building for the purpose of testing out two methods of thoroughly imbedding the lath in stucco and to determine whether these methods may not be preferable to the ordinary method of plastering the lath on one side.

Twenty-one of these additional panels were plastered in accordance with the typical specifications issued about two years ago by the Associated Metal Lath Manufacturers, the essential feature of which was the fastening of the lath and furring directly to studs without the use of sheathing, the lath being back plastered immediately after the scratch coat had set.

The remaining panels were backed up with sheathing, the greater part of which could be removed after the plastering was finished. The outside of the wall was then covered with felt and over this ⅜-in. furring was nailed to the permanent sheathing.

The lath was then plastered as usual on the outside, but no hair was used in the scratch coat, and the stucco was mixed as wet as it could be and still hold to the wall without "sliding."

This was well pressed into the lath to fill as completely as possible the entire space between the lath and the sheathing paper. After the stucco had hardened and dried out the removable sheathing was taken down and the sheathing paper cut away, leaving a smooth cement surface wherever the application of the scratch coat had been well done. While not all the spaces were entirely filled by this method the success was greater than anticipated. Eliminating the types of lath which were unsuited to this construction probably 99 per cent of the total area so treated presents the smooth unbroken surface of an interior wall, not even showing the pattern of the imbedded lath. It is evident that a diamond mesh lath, or one all of whose strands slope at the same general angle to the plane of the lath as a whole, should be used if the best results are to be obtained by this method.

As already stated no examination has yet been made of the metal actually imbedded in the plaster or stucco, and the condition of these additional samples will not therefore be determined until later. It is anticipated, however, that both these methods, at least so far as the durability of the lath is concerned, will be found to be more satisfactory than the type of application now commonly specified.

DATA ON LIME PUTTY AND CREAM OF LIME

By Cloyd M. Chapman*

Being unable to locate definite and reliable data as to the volume of putty and cream of lime which a given quantity of quicklime would produce and as it appeared desirable to have such data in the records of the Institute for ready reference for use in specifying cement-lime mortar mixtures for stucco and for other purposes, it was decided to carry out a series of determinations in the Laboratory of Westinghouse Church Kerr and Company to ascertain some of these physical characteristics.

The specific purpose of the tests was to determine certain constants of lime putty and cream of lime, such as the weight per unit volume, weight of lime in a unit volume, volume resulting from slaking and wetting a given weight of quicklime, etc. It was expected that fairly constant values would be determined for each of these various quantities so that by averaging several results a figure might be arrived at which would serve for general use in specifying lime mixtures.

It may be well to insert here that whenever the word is used in this paper it means the commercial article which is defined by the Lime Committee of the American Society for Testing Materials in their tentative specifications as "a product resulting from the calcination, at a temperature below the cindering point, of a material containing carbonates of calcium, or calcium and magnesium, which may be or has been converted to a paste or a dry flocculent powder by slaking."

In carrying out these tests the following procedure was followed:—

Some eight dealers in lime in New York City were requested to forward to the Laboratory 5-lb. samples of their lump lime. These as received were placed in air-tight metal cans to prevent absorption of moisture and air slaking.

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A representative lump was chosen from each sample and its specific gravity determined by the displacement method, using water-free kerosene oil as the liquid. The dry lump of lime was weighed, then immersed in oil for 24 hours to become saturated, excess oil was then wiped from the surface and the lump again weighed. It was then suspended in the oil and weighed again. The difference in weight in grams of the saturated lump in air and in oil divided by the specific gravity of the oil gave the volume in cc. of the lump. The weight in grams dry, divided by the volume in cc. gives the specific gravity. These data were sought merely as a matter of interest, to compare one lime with another.

Another sample of each lime tested was broken to the size of beans, slaked with water in a wide-mouthed bottle to which a reflux condenser was attached so that water evaporated by the heat of slaking would be returned to the bottle. This bottle had a ring mark around its neck at a point representing 300 cc. After cooling, additional water was added to make a paste or putty of a certain consistency which was adopted as a standard for these tests. This consistency was such that with the Chapman Consistency Apparatus a drop of 3 in. would produce a spread of the liner of about 0.25 in. using a cylinder $1\frac{1}{8}$ in. in diameter and 3 in. high. This consistency is one suitable for use in regular work on the job. The flask was then carefully filled with water from a burette up to the 300 cc. mark in order to determine the volume of the putty. This water was run down the side of the flask so as not to mix with the putty. When the flask had been filled the water was carefully decanted, leaving the lime putty in the flask.

This putty was then thinned to the consistency of cream which was also standardized for the test by a method proposed by the writer. This consistency may be very definitely determined as follows:—The paste is thinned gradually by the addition of small amounts of water at a time, taking care to stir the paste sufficiently after each addition of water to bring the mixture to a uniform consistency and break up all lumps. The addition of water is continued until the resulting mixture is of the proper standard consistency which is determined by dipping a wood paddle $\frac{1}{2}$ in. wide by about $\frac{1}{8}$ in. thick (the thin end of a shingle makes a good paddle) into the cream and spooning up what cream can be lifted on the flat side of the paddle, which has been withdrawn from

the cream in an inclined position as a spoon would be lifted. The paddle is now tipped up into a vertical position and if the cream on the paddle flows sluggishly off the end without the assistance of any jarring then the consistency is that sought. If the cream adheres and does not flow then it is too thick, if it flows freely it is too thin.

By this method one particular consistency may be determined with considerable accuracy, but of course the method is not applicable to any other consistency.

After the lime has been thinned to cream of lime the flask is filled to the 300 cc. mark on its neck with water from a burette to determine the volume of cream produced.

During the test the following quantities are taken and recorded. The metric system of weights and measures was used.

a = capacity of flask (300 cc.)
b = weight of empty flask.
c = weight of sample of lime.
d = cc. of water added to lime to make putty.
e = cc. of water added to lime putty to fill flask to 300 cc. mark.
f = weight of flask, lime putty and remaining water after decanting.
g = cc. of water added to putty to make cream of lime.
h = cc. of water added to cream to fill flask to 300 cc. mark.

From these data the following results were computed:

(1) Gallons of water required to make putty of 1 bbl. or 200 lb. or 90,720 g. of lime. (1 gal. being equal to 3798 cc.)

$$\text{Gals. water} = \frac{90720}{c} \times \frac{d}{3786}$$

(2) Pounds of lime in 1 cu. ft. of the putty (1 cu. ft. being equal to 28,320 cc. and one lb. to 453.6 g.).

$$\text{lb. lime} = \frac{28320}{a-e} \times \frac{c+d}{453.6}$$

(3) Weight of 1 cu. ft. of the lime putty.

$$\text{Wt. in lb. per cu. ft.} = \frac{28320}{a-e} \times \frac{(c+d)}{453.6}$$

TABLE I.—RESULTS OF LIME TESTS.

	HIGH CALCIUM CONTENT.									LOW CALCIUM CONTENT.		
Sample No.	117	114	116	118	120	113	119	115		121	124	
Source	York, Pa.	Farnum, Mass.	Farnum, Mass.	Rockland, N. Y.	West Stockbridge, Mass.	York, Pa.	Adams, Mass.	West Stockbridge, Mass.		Dover Plains, N. Y.	Knickerbocker Pa.	
Marked	Chemical Lump Lime	Lump Lime	Lump Lime	Lump Lime	Lump Lime	Lump Lime	Granular Lime	Lump Lime	Average	Dutchess County Lime	Lump Lime	Average
Analysis CaO	99.04	98.91	98.91	96.81	95.23	95.00	94.87	84.31	95.38	56.46	56.99	56.72
MgO	0.65	....	....	1.27	0.71	....	0.84	5.84	1.16	38.54	40.11	39.32
SiO2	0.10	0.73	0.73	0.42	3.46	....	2.05	3.54	1.38	1.58	2.11	1.85
R2O3	0.12	0.36	0.36	0.88	0.60	0.36	1.86	2.00	0.77	1.60	0.79	1 14
Specific Gravity	1.665	1.696	1.575	1.611	1.535	1.638	....	1.742	1.638	1.600	1.516	1.558
Gals. water per bbl. to make putty	29.4	32.2	32.7	30.5	32.4	29.1	32.9	28.3	30.9	25.3	22.8	24.0
Lbs. lime in 1 cu. ft. putty	43.1	38.7	38.0	44.6	41.2	41.8	38.6	45.2	41.4	50.6	56.5	53.5
Wgt. 1 cu. ft. putty in lbs	95.2	93.0	89.3	100.1	96.7	92.2	91.5	97.8	94.4	102.4	109.0	105.7
Gals. water per bbl. to make cream	68.1	75.7	105.8	73.5	96.0	76.4	109.2	73.2	84.7	72.6	37.4	55.0
Lbs. lime in 1 cu. ft. cream	21.0	20.4	13.3	20.0	15.7	19.4	12.9	19.0	17.7	21.5	34.6	28.0
Lbs. lime in 1 gal. cream	2.8	2.84	1.76	3.76	2.08	2.56	2.28	2.52	2.56	2.84	4.4	3.6
Wgt. 1 cu. ft. cream in lbs	78.7	78.9	70.5	78.8	74.3	76.0	71.0	75.9	75.5	77.8	87.8	82.8

(4) Gallons of water required to make cream of 1 bbl. or 200 lb. of the lime.

$$\text{Gals. water} = \frac{90720}{c} \times \frac{\text{d+f}—(b+c+d)+g}{3786}$$

(5) Pounds of lime in 1 cu. ft. of the cream of lime:

$$\text{Lb. lime} = \frac{28320}{a—h} \times \frac{c}{453.6}$$

(6) Pounds of lime in one gallon of the cream of lime:

$$\text{Lb. lime} = \frac{3786}{a—h} \times \frac{c}{453.6}$$

(7) Weight of 1 cu. ft. of the cream of lime:

$$\text{Wt. in lb.} = \frac{28320}{a—h} \times \frac{c+d+f—(b+c+d)—g}{453.6}$$

Each of these determinations was made several times with each lime and the results are shown in Table I. The figures given are in each case the average of the several determinations.

The analyses given were furnished in most cases by the manufacturer, but where this information was lacking the sample was analyzed in the Laboratory.

In the table the first eight samples are what would be termed "high calcium" limes, as they contain 95 per cent or more of CaO, while the other two are "low calcium" or magnesia limes.

An inspection of Table I brings out the following features:

(1) The amount of water required to make putty by the low-calcium limes tested is about 20 per cent less than for the high-calcium limes.

(2) The amount of water required to slake and reduce to a putty one barrel of high-calcium lime is a variable quantity and for the samples tested ranges from 28.3 to 32.9 gals. The average is about 31 gals. and for average conditions this figure may be close enough for most purposes. In the cases of the low-calcium lime this quantity of water is considerably less and averaged for the two samples tested 24 gals.

(3) The weight of high calcium lime in a cu. ft. of putty

ranged from 38.6 to 45.2 lb. and averaged 41.4 lb., which figure is probably a satisfactory one to use on the job. For low-calcium limes the average was 53.5 lbs.

(4) The weight of 1 cu. ft. of putty made from high-calcium lime varied from 95.3 to 100.1 lb. and averaged 94.4 lb. and for low-calcium limes the average was 105.7 lb.

(5) The amount of water required for slaking 1 bbl. of high-calcium lime and reducing it to the consistency of cream was much more variable than in the case of putty and ranged from 68.1 to 109.2 gals. with an average of 84.7 gals. This is too wide a range of variation to permit the use of average figures and secure a sufficient degree of accuracy. This variation was equally marked in the case of low-calcium limes, which averaged 55 gals.

(6) The weight of lime in 1 cu. ft. of cream and in 1 gal. of cream varies indirectly as the volume of water required to reduce the lime to cream and the range is so great that average figures are of little use.

(7) The same is also true, but to a less degree, of the weight of 1 cu. ft. of cream, the range being from 70.5 to 78.9 lb. with an average of 75.5 for high-calcium limes and averaged 82.8 for low-calcium limes. These figures are, however, seldom of use in mixing mortars or concrete, as quantities are usually measured and not weighed.

In order to show graphically the relation between the amount of water used in making a putty of standard consistency from quicklime, and the weight of lime in 1 cu. ft. of the resulting mixture, the results given in Table I were plotted as shown in Fig. 1 by the longer of the two curves.

Plotting the gallons of water required to make putty of one barrel of lime as ordinates and the pounds of lime in one cubic foot of the putty as abscissae, the values of both being taken from Table I, give the points enclosed in circles in Fig. 1 for the high-calcium limes, and the points enclosed in triangles for the lowe calcium or magnesian limes.

In the same manner by plotting the gallons of water required to make cream of lime of one barrel as ordinates and the pounds of lime in one cubic foot of the cream as abscissae we get the points enclosed in squares for the high-calcium limes and the points in diamonds for the low-calcium limes.

(Concluded in next issue.)